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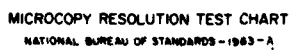
THE EFFECT OF SUBSTITUTING THE DD FORM 250 ACCEPTANCE  
RATE FOR ACTUAL PRO. (U) AIR FORCE INST OF TECH  
WRIGHT-PATTERSON AFB OH SCHOOL OF SYST. G D GENTRY  
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**THE EFFECT OF SUBSTITUTING THE  
DD FORM 250 ACCEPTANCE RATE  
FOR ACTUAL PRODUCTION RATE  
WHEN PREDICTING DIRECT LABOR  
REQUIREMENTS FOR MISSILE PRODUCTION  
PROGRAMS**

**Giles D. Gentry, Jr., Captain, USAF**

**LSSR 97-83**

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↙ The addition of the production rate variable to the standard learning curve model has been validated as a significant improvement in estimating direct labor hours for airframes, avionics equipment, aircraft engines, and missiles. This research set out to determine if acceptance rate of the end item could serve as a reliable proxy for the production rate variable when production rate data are not available to the researcher. Acceptance rate, as reported on DD Form 250, was substituted for production rate data in a replication of research on the Maverick missile program. Research results failed to support the reliability of the acceptance rate proxy for this program. ↗

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PROGRAMS**

**A Thesis**

**Presented to the Faculty of the School of Systems and Logistics  
of the Air Force Institute of Technology**

**Air University**

**In Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Logistics Management**

**By**

**Giles D. Gentry, Jr., BBA  
Captain, USAF**

**September 1983**

**Approved for public release;  
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This thesis, written by

Captain Giles D. Gentry, Jr.

has been accepted by the undersigned on behalf of the faculty  
of the School of Systems and Logistics in partial fulfillment of  
the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT  
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DATE: 28 September 1983

Robert B. Weaver  
COMMITTEE CHAIRMAN

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## CHAPTER I

### INTRODUCTION AND OVERVIEW

The learning curve has been used extensively in the aircraft industry during the last thirty years to assist in cost estimating for major DOD weapons acquisition programs. Since the introduction of the basic learning curve model, a number of variations have been developed in an attempt to achieve a greater accuracy in predicting actual cost figures [7:6].

The post-World War II years constitute an era of increasing complexity in Department of Defense (DOD) weapon systems acquisitions. Although primary concern has centered on the effective and efficient use of taxpayer dollars, numerous obstacles make this objective difficult to achieve. Tremendous leaps in technology have resulted in weapon systems of previously unimaginable complexity and cost. Further complicating the issue is the need to plan the acquisition and use of these weapon systems over as much as a twenty-year time span with money that is appropriated one year at a time. Even more uncertainty has been added by shocks to the U.S. economy in the form of (1) inflation, (2) increasing cost and questionable availability of energy, and (3) increased competition from foreign countries (2:1).

These conditions contribute to cost overruns in DOD weapons systems acquisitions and clearly illustrate the need for more precise techniques to estimate weapon systems cost. The experience of industry and the DOD

- indicates that direct labor is a significant determinant of cost. This research will focus on developing a more accurate way to estimate direct labor costs, and, more specifically, the effect of the absence of production rate data on estimating these direct labor costs.

#### LIMITING THE PROBLEM

At the outset of a major DOD production program, a tentative monthly production schedule for the life of the program is negotiated between the contracting parties. This schedule permits planning for such items as work force build-up, facility and tooling needs, and the ordering of long lead items. Although the planning delivery schedule covers the life of the program, formal contractual agreements between the DOD and manufacturers usually cover only annual delivery requirements. Delivery requirements for subsequent years are funded through the exercise of options or separate contracts as funds are appropriated by the Congress (14:2).

These multiple year programs may result in a need to change the production rate. For example, when funding for a particular year is insufficient to cover the production schedule under an existing production plan, it may be necessary to stretch out the production over a longer time span. A national emergency or changed mission requirement



may dictate an accelerated rate of production. When such changes in delivery schedules are required, changes in cost estimates are also required to support contract negotiations and additional funding requests. It is suggested that the rate of production is an important independent variable that can be used to help project the change in unit costs due to either program accelerations or decelerations (14:2). In some instances, however, when actual production rate data are not available, it is not known if a reliable proxy exists to serve for these data.

Industrial and government cost estimators have traditionally used learning curve techniques to estimate direct labor hours required in production (4:25). Learning curve theory is derived from the relationship between the cumulative number of units produced and the number of direct labor hours required for production. In other words, as a worker produces more of a given item, a certain amount of "learning" (proficiency) occurs, and the number of hours required for production tends to decrease in a regular pattern. Learning curve theory is based on the following assumptions:

- (1) The production item should be sizeable and complex and should require a large amount of labor.

- (2) The majority of assembly operations should not be mechanized or machine-paced.

(3) Learning curves applied from past experience should be adjusted for any differences in items, processes, or other aspects of production.

(4) The production process should be a continuous one and the item and product changes kept to a minimum.

(5) Historical data should be available to compute the curve, since estimated data have low reliability.

(6) There should be no external production rate changes (4:231).

The last assumption is unrealistic for DOD weapon systems acquisition. Changes in production rate are forced on DOD activities quite often. There has been considerable research conducted to correct this apparent limitation of the standard learning curve model (2:4). These studies will be discussed later in this chapter.

One of the most promising studies, by Larry L. Smith, resulted in a model for airframe production which improved the basic learning curve model through the addition of a production rate variable. Smith's methodology has been replicated for aircraft avionics, engines, and missile systems to determine its validity in other types of production. Further replication, using proxies as a substitute for the actual production rate variable is warranted, and forms the basis of this research effort.

### STANDARD LEARNING CURVE MODEL

T. P. Wright is generally regarded as the pioneer of learning curve theory. After his initial research, learning curve tables were used at McCook Field, Dayton, Ohio as early as 1925 (5:49-50). Wright's 1936 article on the application of the learning curve to aircraft manufacturing cost estimation is widely regarded as the initial substantive effort in mathematically modeling the learning phenomenon for aircraft manufacturing (16:2D26). As a result of increased aircraft production during World War II, the U.S. Government sponsored a statistical analysis by the Stanford Research Institute on World War II airframe direct labor data. The Stanford study resulted in two important achievements: (1) it confirmed the learning curve effect on World War II production, and (2) it demonstrated the value of a learning curve model for use in cost analysis (16:2D26-27).

It can be intuitively discerned that for labor production processes which are repetitious, each successive equivalent unit of production will require fewer direct manhours, and that the manhours required decrease at a decreasing rate. This phenomenon, known as the learning or experience curve, has two basic variations. The variation validated by the Stanford study is known as the "unit curve" or the "Boeing theory", and can be expressed mathematically by the formula:

$$Y = AX^b$$

where:

Y represents the direct labor hours for the "xth" unit,

- X represents the total number of units manufactured in the process,
- A represents the number of labor hours to produce the first unit manufactured in the process, and
- b represents the slope parameter or a function of the improvement rate [2:7].

The slope of the curve can be expressed as a percentage, which is the ratio between the per unit cost at any unit and the percent cost at double that number of units [3:199].

The "cumulative average" or "Northrop" variation (described by Wright in his 1936 article) measures the average cost for X units rather than the cost for the xth unit. Its mathematical form is:

$$\bar{Y} = AX^B$$

where:

- $\bar{Y}$  represents the cumulative average cost of all production up to and including the xth unit.

The other parameters are the same as for the unit curve theory [2:7].

While the Boeing and Northrop models can be manipulated in the same manner, the user should be aware of the difference between the unit cost and the cumulative unit cost measured by these respective models [7:7-9].

As stated above, the basic learning curve model can be manipulated by either unit cost or cumulative unit cost. The unit learning curve (unit cost) of the basic learning curve will be the model used for the remainder of this paper. Also, for purposes of this research, the basic learning curve model will later be referred to as the "reduced model."

### Limitations of the Standard Learning Curve Model

Probably due to its simplicity, intuitive appeal, and long history, the basic learning curve model is still widely used. However, the learning curve model does not take into account the exogenous changes in the rate of production. Those exogenous changes are a concern to researchers because of their effect upon the total direct labor requirements.

Concern about exogenous changes in production rate is justified by the following factors: (1) workers will adjust according to pressure to speed up or slow down production; (2) as more workers are employed, the distribution of tasks to each individual worker should narrow; and (3) at higher production rates, tooling costs and set-up costs can be more widely allocated to larger number of units.

Fiscal prudence dictates that each echelon within DOD strive for accurate cost prediction in order to budget, manage, and control. It naturally follows that the importance of production rates in cost estimating must be investigated fully, and that DOD buyers must consider the effects of production rate changes throughout the acquisition process [15:11].

### HISTORY OF EFFORTS TO ADD PRODUCTION RATE VARIABLE

The focus of this research involves the addition of the production rate variable, in the form of a proxy, as a second independent variable in the learning curve model. This section will present a chronological history of some of the more important work that has been done in this regard. The list is not exhaustive, and is intended only to provide the reader with a summary of the most widely recognized research efforts in this field. Not all researchers have agreed as to the usefulness of the production rate variable. However, recent efforts show

great promise for the production rate to aid in more accurate predictions of labor requirements. If this research effort substantiates the contention that a proxy can be used in place of the production rate variable in the learning curve, DOD researchers will have the opportunity to complete research efforts where the production rate variable is not available.

#### Harold Asher (1956)

Asher examined the relationship between cost and quantity in the airframe industry. Using empirical data from several airframe production programs, he subjectively evaluated the effect of the production rate on direct labor hour requirements. Asher identified two ways in which the production rate could affect unit labor cost. First, it can affect the amount of machine set-up time charged to each unit of production. Second, it can affect the number of subassemblies in the manufacturing process, which, in turn, affects the number of hours of subassembly work charged to each unit. He concluded that production rate was not very important as a predictor when compared to the effect of cumulative production (3:86-87).

#### Alchian and Allen (1964)

Alchian and Allen advanced the idea that production cost is dependent on three production variables: (1) total volume of the item to be produced, (2) production rate,

and (3) amount of time from the decision to produce until the first output occurs (14:19). They drew three major conclusions. First, larger total volumes lead to smaller unit costs because of increased product standardization that accompanies larger volume. Second, unit costs increase with increasing production rates because more overtime and less efficient workers are needed to support the increased production rate. Third, the cost variable increases if the initial production start-up time is compressed. They explained that less efficient procedures are used than if time were allowed to prepare properly for production. Subsequent effort expended to correct these inefficiencies results in higher unit costs (1:308-322).

Although Alchian and Allen did not test their conclusions on actual data, their ideas may have application to the airframe industry (14:20).

Gordon J. Johnson (1969)

Johnson predicted labor requirements for rocket motors using an additive model which considered both the rate effect and the learning effect. The model he used was:

$$y = A + BX_1 + CX_2^Z$$

where:

y represents direct labor hours per month,

$X_1$  represents production rate in equivalent units per month,

$X_2$  represents cumulative units produced as of the end of the month, and

A, B, C and Z are model parameters.

Johnson regressed this model against four sets of rocket motor data. His results are shown in Table I. As depicted in the table, Johnson had good results (high  $R^2$ ) with data sets 1 and 4, fair results with data set 2 and poor results with data set 3. Johnson explained data set 3's poor results as being due to an inadequate accounting system used by the manufacturer. He concluded that the production rate is a significant determinant of direct labor requirements [7:10].

#### Joseph A. Orsini (1970)

Orsini (12:57-80) tested Johnson's rocket motor model using airframe data from the C-141 program. He employed the following procedure: (1) regression analysis was performed on the data using the standard unit learning curve model, (2) regression analysis was again performed using Johnson's three dimensional additive model that incorporated rate of production, and (3) analysis was performed after converting Johnson's additive model into a multiplicative one which is stated as follows:

$$Y = e^{B_0} \cdot X_1^{B_1} \cdot X_2^{B_2}$$

where:

Y represents the direct labor hours per quarter,

$X_1$  represents the number of units produced per quarter,

$X_2$  represents the cumulative number of units produced as of the end of the quarter,



**TABLE 1**  
**SUMMARY OF JOHNSON'S REGRESSION ANALYSIS**

Regression Variables	Coefficients of Determination ( $R^2$ )			
	Data Set			
	1	2	3	4
Labor Hours vs. Cumulative Units	.753	.395	.0067	.763
Labor Hours vs. Cumulative Units and Production Rate	.932	.808	.308	.927

Source: [9:34].

$B_0$ ,  $B_1$ , and  $B_2$  are model parameters and  $e$  is the base of the natural logarithms [2:11-12].

Orsini concluded that (1) inclusion of the production rate as an independent variable significantly improved the predictive ability of both the additive and multiplicative models, and (2) the multiplicative model performed better as a predictor than did the additive one because it eliminated the need to estimate the parameter  $Z$  (12:71).

Large, Hoffmayer, and Kontrovich (1974)

During an effort to develop a general model, Large, Hoffmayer, and Kontrovich examined data from major airframe acquisitions relating to the effect of production rate on cost. The model used, according to Smith (14:29-30), is of the form:

$$Y_i = A \cdot w^B \cdot s^C \cdot r^D$$

where:

- $Y_i$  represents the cumulative direct manufacturing labor hours through unit number  $i$ ,
- $w$  represents the program average Defense Contractor Planning Report (DCPR) weight expressed in pounds,
- $s$  represents the maximum design airspeed in knots,
- $r$  represents the production rate expressed as the acceptance span in months for the first  $i$  airframes.

(For their investigation, Large, Hoffmayer, and Kontrovich chose  $i$  arbitrarily to be 100 or 200), and

$A$ ,  $B$ ,  $C$  and  $D$  are model parameters [2:12].

Large, Hoffmayer, and Kontrovich concluded that the effects of the production rate could not be predicted with confidence, especially in the early stages of a major acquisition. They concluded that each case must be considered separately (10:50-51). Smith (14:31) indicated that the use of an acceptance span as a proxy for production rate masked the true effect of the production rate because of the resultant averaging effect.

Joseph Noah

Noah analyzed cost data to find the effect of production rate on airframe costs. His model for the data was:

$$y = e^A \cdot x_1^B \cdot x_2^C \cdot x_3^D$$

where:

y represents average direct labor hours per pound of airframe for each airframe lot,

e is the base of the natural logarithm,

$x_1$  represents the cumulative volume in pounds of aircraft produced by the midpoint of each airframe lot,

$x_2$  represents the production rate in average pounds of airframe delivered per month for the entire period,

$x_3$  represents the annual volume of aircraft in airframe pounds, and

A, B, C, and D are model parameters.

Noah averaged the estimated regression coefficients from two sets of data, one on the F-4 and the other on the A-7, and tried to develop a generalized cost model. Smith felt

that this approach was questionable and that the model needed to be tested on additional aircraft programs to determine if it did actually serve as an accurate predictor. Also, Smith stated that while the lot average airframe delivery rate was a practical representation of the production rate, the average delivery rate variable appeared to lag the average expenditure of hours required to produce the airframes delivered [7:10,12].

Larry L. Smith (1976)

Smith developed a model for airframe production that included a production rate variable to test the idea that production rate changes can explain changes in direct labor requirements (14:35). He adapted a modified version of Orsini's multiplicative model as follows:

$$Y_i = B_0 \cdot X_{1i}^{B_1} \cdot X_{2i}^{B_2} \cdot 10^{e_i}$$

where:

- $Y_i$  represents the unit average direct hours needed to output each pound of airframe in lot i,
- $X_{1i}$  represents the cumulative learning accrued from experience on all airframes of the same type through lot i,
- $X_{2i}$  represents the production rate of lot i for all airframes of the same type,
- $e_i$  represents the variation of each dependent variable which is not explained by the two independent variables,

$B_0$ ,  $B_1$ , and  $B_2$  are parameters in the model [14:43].

Smith also linearized the model to facilitate multiple linear regression. The linearized form was:

$$\text{Log } Y_i = \text{Log } B_0 + B_1 \text{ Log } X_{1i} + B_2 \text{ Log } X_{2i} + e_i \text{ (14:45).}$$

To test the accuracy of his model versus the standard learning curve model, Smith employed a "reduced" model which was merely his model, or "full" model, minus the production rate variable. The "reduced" model was a unit learning curve model as follows:

$$Y_i = B_0 \cdot X_{1i}^{B_1} \cdot 10^{e_i} \text{ (13:43).}$$

Regression of historical data with each model allowed Smith to identify the contribution of predictive ability by the production rate variable (15:17-18).

Evaluating data from the F-4, F-102, and KC-135 airframe production programs, Smith reached the following conclusions: (1) in each case, the production rate variable was negatively correlated with unit direct labor requirements, (2) both proxies to the production rate variable were important contributors to the full model's predictive ability, and (3) as evidenced by the  $R^2$  values he obtained, the full model more closely fit the data than the reduced model (14:142-146). Tables 2 and 3 summarize Smith's regression analysis and predictive ability test results.

#### Congleton and Kinton (1977)

Using the same methodology, Congleton and Kinton replicated Smith's research for the T-38 and F-5 airframe

production programs. They reached the same basic conclusions as Smith; however, in one of the thirty test situations they reported that  $R^2$  was higher for the reduced model than for the full model, but by less than one percent (6:91-93).

Stevens and Thomerson (1979)

Stevens and Thomerson replicated Smith's model for aircraft avionics systems. Specifically, they examined the Magnavox ARC-164 radio, applying the methodology set forth by Smith. Stevens and Thomerson formed the following conclusions: (1) production rate was a significant factor in explaining variations in direct labor hours in nine out of ten cases, (2) the predictive ability of the full model was better than that of the reduced model for eighteen months into the future, (3) the standard learning curve (reduced) model consistently overestimated direct labor hours while the full model stabilized predictions over an extended interval, (4) regression coefficients are unique to the program for which they are derived, and (5) the overall applicability of Smith's model has wide potential and can be tailored to various other programs (15:102-104).

Crozier and McGann (1979)

Crozier and McGann also replicated Smith's research. They applied both the reduced model (standard learning

TABLE 2  
SUMMARY OF SMITH'S REGRESSION ANALYSIS†

Test Situation Number	Data Points	$R_f^2$ (actual)	$R_r^2$ (actual)	$B_o$	$B_1$	$B_2$
1	57	0.978	0.928	masked*	-0.261	-0.169
2	55	0.973	0.904	"	-0.246	-0.183
3	55	0.966	0.904	"	-0.257	-0.161
4	42	0.853	0.585	"	-0.230	-0.157
5	42	0.820	0.585	"	-0.229	-0.136
6	42	0.889	0.618	6.328	-0.221	-0.148
7	42	0.851	0.618	7.601	-0.219	-0.127
8	42	0.744	0.658	9.016	-0.279	-0.112
9	42	0.733	0.658	10.400	-0.278	-0.097
10	50	0.979	0.961	38.371	-0.299	-0.158
11	42	0.979	0.959	47.290	-0.344	-0.144
12	96	0.958	0.971	13.133	-0.453	-0.164
13§	7	0.974	0.903	0.674	-0.165	-0.305
14§	7	0.971	0.903	1.123	-0.233	-0.222
15§	7	0.994	0.964	13.338	-0.608	-0.361
16§	7	0.992	0.964	7.303	-0.527	-0.262

\*The total production hours per pound were considered proprietary by the manufacturer, and these coefficients were masked in the published version of Smith's research (15:65).

†Smith's methodology, production rate proxies, and  $R^2$  versus  $R^2$  (actual) are all recapped in Chapters II and III of this research. The subscripts for  $R^2$  are as follows: f stands for full model; r for the reduced.

§Impractical for test situations.

Source: [2:16].

TABLE 3  
SUMMARY OF SMITH'S PREDICTIVE ABILITY  
TEST RESULTS

Test Situation Number	<u>Percentage Deviation*</u>	
	Full Model	Reduced Model
1	-2.6	14.5
2	2.2	13.6
3	Not Reported	13.6
4	1.8	5.3
5	3.1	5.3
6	-7.8	Not Reported
7	†	Not Reported
8	-0.7	1.1
9	-4.2	1.1
10	-1.1	5.6
11	3.5	Not Reported
12	2.2	-3.3
13-16	§	§

\*These tests were conducted as described in Chapter II of this research. All percentages are rounded to nearest tenth.

†Smith reported the results were deviations greater than those for test situation 6, but did not report a value (14:96).

§Smith reported that predictive ability tests were impractical for situations 13 through 16 because observations were limited to seven (14:71-131).

Source: [2:16].



curve) and the full model to three aircraft engine programs: (1) the General Electric J-79, (2) the Allison TF-41, and (3) the Pratt and Whitney F-100. They found that the production rate significantly explained variation in direct labor hours in three of the six cases examined, with especially good results on the F-100 engine. On engine programs, the full model was a better predictor than the reduced model. Crozier and McGann concluded that the results when using Smith's model depend a great deal on the type of weapons system. This last finding justifies the need for more replication efforts of Smith's model (7:92-94).

Allen and Farr (1980)

The findings of Allen/Farr are crucially important to this research effort. They replicated Smith's model for the Maverick and SRAM missile programs, utilizing twelve models in their research methodology. Smith's model was replicated for the fabrication, assembly, and test components of the two missile programs and Allen/Farr concluded that the production rate was found to explain a significant amount of variation in direct labor hours in nine of the twelve models examined. Enough support was evident to conclude that the production rate variable should be considered when evaluating missile production programs. Whereas Allen/Farr used the production rate as

the second independent variable in the full model, this research will use their data and substitute a proxy for the production rate variable. This substitution will test the reliability of the proxy as a substitute when production rate data are not available. The details of this proxy and its application to the model are discussed later in this paper.

#### RESEARCH PROBLEM STATEMENT

Past research efforts have shown that changes in production rate affect direct labor hours for continuing weapon systems production programs. These past research efforts used the number of end items completed during an accounting month as their measure of production rate. This measurement of production rate is not always accessible for the following reasons: (1) the contractor may be unwilling to furnish the data, or (2) the contractor may not collect the data in a format suitable for use in learning curve analysis. Whenever the actual production rate data is not available, a proxy must be employed in its place. One easily accessible proxy for actual production rate is the DD Form 250 acceptance rate. This form is always used in DOD weapon system production programs to document end item acceptance and is readily available to DOD researchers. The use of a proxy, such as

the DD Form 250 acceptance rate, in lieu of actual production rate data in predicting direct labor hours for continuing weapon system production programs is not known.

#### RESEARCH OBJECTIVE

The objective of this research is to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.

#### RESEARCH HYPOTHESIS

The predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

#### PLAN OF DEVELOPMENT

With the problem narrowed and the objective outlined, the next chapter is devoted to a discussion of the methodology for testing the research hypothesis. A brief summary of assumptions and limitations about the methodology will close Chapter II. Chapter III will contain the data analysis and evaluation. Finally, Chapter IV will contain the summary, conclusions, and recommendations of this research.

## CHAPTER II

### RESEARCH METHODOLOGY

This chapter outlines the procedures used to test the research hypothesis. The chapter is divided into five sections as follows:

- (1) Restatement of Objective,
- (2) Model Definition, Variables, and Assumptions,
- (3) Data Collection,
- (4) Analysis Methodology, and
- (5) Summary.

#### RESTATEMENT OF OBJECTIVE

The objective of this research is to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.

#### MODEL DEFINITION, VARIABLES, AND ASSUMPTIONS

##### Model Definition

Chapter I discussed the two models used by Smith, which he called the "full model" and the "reduced model." For ease of reference, the two models are repeated.

The reduced model is the basic learning curve stated as:

$$Y_1 = B_0 \cdot X_{11}^{B_1} \cdot 10^{e_1}$$

In the full model, the production rate variable is added as follows:

$$Y_i = B_0 \cdot X_{1i}^{B_1} \cdot X_{2i}^{B_2} \cdot 10^{e_1}$$

#### Model Variables

The three variables used in this analysis were:

(1) direct labor hours per missile produced, (2) cumulative number of missiles produced, and (3) the DD Form 250 acceptance rate as a proxy for the missile production rate. Since it was considered desirable to improve the ability to predict the direct labor hours required per missile, direct labor was treated as the dependent variable. Cumulative missiles produced and the acceptance rate were considered the independent variables.

The Direct Labor Hours Variable. Direct labor is usually measured in hours, although it is occasionally measured in dollars. Whenever the data are expressed in dollars, care must be taken to accurately account for inflation. The primary determinants of total direct labor are (1) fabrication labor, (2) assembly labor, and (3) test labor. Depending on the individual contractor, the data may be expressed as total labor or any combination of the component parts (fabrication, assembly, and test). The exact measure of the data is unimportant as long as a consistent unit of measurement is maintained (2:21). This

research will measure total direct labor in hours. Referring again to the reduced and full models, direct labor is depicted by the variable  $Y_i$ .  $Y_i$  represents direct labor hours required for each missile, where:

$Y_t$  = total direct labor hours per accounting month,

$Y_{tu}$  = unit index portion of total direct labor hours per accounting month,

$Y_{tsh}$  = standard hours portion of total direct labor hours per accounting month,

$Y_f$  = fabrication direct labor hours per accounting month,

$Y_{fu}$  = unit index portion of fabrication direct labor hours per accounting month, and

$Y_{fsh}$  = standard hours portion of fabrication direct labor hours per accounting month.

The Cumulative Output Variable. Records are normally kept for the number of missiles completed each month. The cumulative output is the total number of missiles completed since the beginning of the production program as of the end of a specific accounting month (2:22). The cumulative output variable is depicted by the variable  $X_{1i}$  and represents the cumulative output of all missiles through the  $i^{th}$ .

The Acceptance Rate Variable. The production rate is the number of missiles completed during an accounting month. For some production processes, the production rate is difficult to accurately assess. Whenever this situation occurs, a proxy must be developed for the production rate.

Commonly used proxies are the delivery rate and the acceptance rate (2:22). The production rate variable used in this research effort will be the missile acceptance rate, earlier referred to as the DD Form 250 acceptance rate. The acceptance rate is depicted by the variable  $X_{2i}$  and represents the acceptance rate of the missiles in group  $i$ .

Miscellaneous Variables.  $e^i$  represents the variation which is left unexplained by the variables in the model and  $B_0$ ,  $B_1$ , and  $B_2$  are the regression coefficients for the model.

In order to use multiple linear regression to analyze the two models, they were transformed to a linear form by taking the logarithm of each term. The logarithmic form of the reduced model is:

$$\text{Log } Y_i = \text{Log } B_0 + B_1 \text{ Log } X_{1i} + e_i .$$

The logarithmic form of the full model is:

$$\text{Log } Y_i = \text{Log } B_0 + B_1 \text{ Log } X_{1i} + B_2 \text{ Log } X_{2i} + e_i .$$

### Assumptions

The statistical significance of the results of the regression will be tested using appropriate F-distribution statistics. To establish the validity of these tests, it is necessary to make some assumptions concerning the error terms in the model. First, the error terms are assumed to be normally distributed with a mean of zero and equal

variance. Second, the error terms are assumed to be independent of each other and of the independent variables (11:30-31).

A third assumption concerns a problem which frequently develops in multiple linear regression, that of multicollinearity. Multicollinearity exists when there is a high correlation between or among independent variables, which in this research are cumulative output and acceptance rate. If a strong correlation exists between or among independent variables, the F-test may find the marginal contribution of one or more variables to be statistically insignificant when, in fact, they may be good explainers of variation in the dependent variable if considered separately (11:341).

While multicollinearity can be a serious problem if the model is to be used for control, it is not as serious a problem when the purpose of the model is to predict, as is the case in this research (11:342). The contribution made by adding the acceptance rate to the reduced model will be subjectively evaluated by comparing predictions of the reduced model to those of the full model. Therefore, it is assumed the varying degrees of multicollinearity will have no substantial impact on the short-range predictive abilities of the models (2:24).



### DATA COLLECTION

As in all previous research using Smith's model, accessibility of data is a very important determinant in selecting the particular program to be studied. The data must be the actual historical data rather than estimates. The data represents a census rather than a sample and statistics derived for each individual population are, therefore, descriptive of only that population. Consequently, the information derived is applicable only to the program being studied in this research. The regression coefficients found in this research must not be indiscriminately applied to other missile production programs.

The data furnished by the Hughes Aircraft company consisted of total direct labor requirements and production history for the total Maverick missile production. Full-scale production commenced April 1972 and continued without interruption through May 1978 (73 months), resulting in the manufacture of 26,500 units. During the 73 months of production, the government accepted 68 deliveries using the DD Form 250.

This research effort uses the same data as used by the Allen/Farr team in their research except for production rate. Where Allen/Farr used actual production rate, this research uses the DD Form 250 acceptance rate

as a proxy for actual production rate. Because the data reflected significant fluctuation in the acceptance rate, the Maverick program provides an excellent test situation for this comparative research. In the Allen/Farr research, the Maverick data were broken down into several major components: fabrication, assembly, and test. These three components were then incorporated into a total model. This research models only the fabrication component and the total model used in the Allen/Farr effort. Funding limitation precluded incorporating the assembly and test components into this research.

One intriguing aspect of the Maverick data was the manner in which the manufacturer accounted for direct labor hours. Direct labor hours were segmented into two components: Unit Index and Standard Hours. On a continuing basis, Hughes conducted time and motion studies to estimate how many hours it would take to manufacture each missile under "ideal" conditions at a particular point in the production program. This estimate was called Standard Hours, and its evolution over time represented a measure of methods improvement. For each month of production, Hughes computed a Unit Index reflecting the deviation between actual number of direct labor hours required for production and the number of hours that would be required under ideal conditions. Whenever the actual number of

hours required for production achieved the "ideal" standard, the Unit Index was equal to one. Any value of the index greater than one reflected less than ideal performance. The evolution of the index over time represented a measure of labor improvement or learning. To calculate direct labor hours per missile, the Unit Index was multiplied by the Standard Hours. For example, assume the program is in the early stages of production, the Standard Hours are 100 hours per unit and the Unit Index is 2.50 per unit (less than perfect conditions). The two are then multiplied to calculate total hours per missile of 250.

As one might expect, the Unit Index, Standard Hours, and direct labor hours exhibited learning trends to varying degrees. Because of this unique accounting procedure, Allen and Farr were able to assess the effects of the production rate on both the "labor learning" and "methods improvement" aspects of direct labor (2:39). The same advantage holds for this research because of the simplicity of substituting the acceptance rate proxy for actual production rate.

The raw data are transformed into logarithmic form to be used in six different models for this research. The first three models are labeled as follows:

Model One: Total Hours Per Unit,  
Model Two: Unit Index for Total Hours Per Unit, and  
Model Three: Standard Hours for Total Hours Per Unit.

The last three models are labeled as follows:

Model Four: Fabrication Hours Per Unit,  
Model Five: Unit Index for Fabrication Hours Per  
Unit, and  
Model Six: Standard Hours for Fabrication Hours  
Per Unit.

Regression analysis is performed on both the reduced and the full forms of the models, and test statistics are calculated. The test statistics are then compared with the critical values required, and the criterion tests are applied to determine if the model is acceptable for testing. If the results for a particular model support its acceptability and the criterion tests fail to reject the model as inappropriate, that model is then tested for its predictive ability. The statistical tests, criterion tests, and their objectives for this research effort are discussed in detail in the following section.

#### ANALYSIS METHODOLOGY

The hypothesis to be tested in this research is that the predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

Testing this hypothesis first requires determining if the model, using the DD Form 250 acceptance data, is acceptable. Then, if the model is found to be acceptable, the predictive ability of the model is compared to the predictive ability of the model using actual production rate data to determine if any compromise exists.

To determine if a model using the DD Form 250 acceptance rate is acceptable requires two steps. The first step examines the statistical significance of the model's regression coefficients by regression analysis of historical production data. This step is composed of two statistical steps. The second step involves the use of two criterion tests to evaluate the appropriateness of the model for this data. The dependent variable of the full model, in log-linear form, will be subjected to regression analysis. The independent variables are the logarithms of cumulative output and the DD Form 250 acceptance rate.

### MODEL ACCEPTABILITY TESTING

#### Statistical Tests

The first statistical test (ST1) examines the relationship between the cumulative output and acceptance rate variables and the direct labor hour variable as shown in the model. The null hypothesis and its alternate are formed as follows:

$H_0: B_1 \text{ and } B_2 = 0$

$H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$  .

This hypothesis will be tested using the following format:

- (1) State the null and alternate hypothesis.
- (2) State the alpha level (level of significance).
- (3) State the test statistic. The test statistic for statistical test one will be the F-test.
- (4) State the Decision Rule. If the F-ratio is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
- (5) State the Decision based upon the Decision Rule.

Mathematically,  $F\text{-ratio} = MSR/MSE$ ,  $MSR = SSR/p-1$ , and  $MSE = SSE/n-p$  where:

MSR represents the mean of the regression sum of squares in logarithmic form,

MSE represents the mean of the error (or residual) sum of squares in logarithmic form,

SSR represents the regression sum of squares in logarithmic form,

SSE represents the error (or residual) sum of squares in logarithmic form,

n represents the number of observations, and

p represents the number of parameters in the model (11:45, 79, 227-228).

The F-ratio compares the explained variance (MSR) to the unexplained variance (MSE), and thus determines the ability of the model to explain the variance of the dependent variable (2:26).

The second statistical test (ST2) tests the ability of the DD Form 250 acceptance rate variable, when combined with the cumulative output variable, to explain additional variation in direct labor hours per missile. Statistically, the null and its alternate hypotheses are:

$$H_0: B_2 = 0$$

$$H_A: B_2 \neq 0$$

This hypothesis will be tested using the following format:

- (1) State the null and alternate hypotheses.
- (2) State the alpha level (level of significance).
- (3) State the test statistic. The test statistic for statistical test two will be the F-test.
- (4) State the Decision Rule. If the F-statistic is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .

- (5) State the Decision based upon the Decision Rule.

The value of  $F^*$  is determined as follows:

$$F^* = \frac{\Delta R^2 / g}{(1 - R^2) / (n - k - 1)}$$

where:

- $\Delta R^2$  represents the increase in explained variations caused by the addition of the logarithm of the acceptance rate variable to the reduced model,
- $g$  represents the number of variables (in this case, one) which cause the increase in  $R^2$ ,
- $n$  represents the number of observations,
- $k$  represents the total number of regressors, and

$n-k-1$  represents the degrees of freedom in the unexplained variation (17:435).

The  $F^*$  statistic in this test yields a ratio of the increase in explained variance to the remaining unexplained variance which resulted from introducing the acceptance rate variable into the reduced model (2:27).

#### Criterion Tests

The first criterion test (CT1) for the appropriateness of the model concerns the assumptions about the residuals, or observed errors. The model is considered appropriate for the data if the assumptions about constant variance of residuals, independence of residuals, and normal distribution of residuals cannot be rejected on the basis of appropriate tests (11:240).

The assumption of constant variance of residuals is tested by plotting the residual values against the predicted values of the dependent variable. The assumption is accepted if the plot revealed an even distribution (no discernible pattern) and if most residuals are within one standard error of the estimate (11:239-240).

The Durbin-Watson Test (2:28) was used to check for independence of residuals. The test determined whether or not the autocorrelation parameter  $\rho$  was equal to zero. The test alternatives were:



$$H_0: \rho > 0$$

$$H_A: \rho = 0$$

This portion of criterion test one (CT1) will be tested using the following format:

- (1) State the null and alternate hypotheses.
- (2) State the alpha level (level of significance).
- (3) State the test statistic. The test statistic for criterion test one will be the Durbin-Watson statistic.
- (4) State the Decision Rule. If  $D$  is greater than  $d_L$ , conclude  $H_A$ ; if  $D$  is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) State the Decision based upon the Decision Rule.

A statistical package called "STAT II" in the Copper Impact Library at the Air Force Institute of Technology calculated the Durbin-Watson statistic designated as  $D$ . Table A-6 in the Neter and Wasserman text contained upper and lower bounds ( $d_U$  and  $d_L$ ) for various sample sizes, levels of significance, and numbers of independent variables. The calculated  $D$  statistic was compared to the upper and lower bounds in the table at the 0.05 level of significance. If  $H_A$  was concluded, the residuals were considered to be independent (2:29).

The assumption of normal distribution of residuals was tested through the Kilmogorov-Smirnov (KS) test. The

basis of the KS estimation procedure is the cumulative sample function, which is denoted by  $S(X)$ .  $S(X)$  specifies for each value of  $X$  the proportion of values less than or equal to  $X$ . The KS procedure utilizes a statistic, denoted by  $D(n)$ , which is based on the differences between the cumulative sample function  $S(X)$  and the true cumulative probability function  $F(X)$ .

$$D(n) = \text{Max } |S(X) - F(X)| .$$

In other words,  $D(n)$  equals the largest absolute deviation of  $S(X)$  from  $F(X)$  at any value of  $X$ .  $D(n)$  is shown as a function of  $n$  because it depends on the sample size. Surprisingly, however, it does not depend on the specific form of  $F(X)$ . Hence, the KS procedure may be used for goodness of fit tests for any shape distribution, and will be used in this case to see if the residuals were normally distributed (2:29).

The KS statistic used in this research was calculated by the STAT II package in the Copper Impact Library. If the calculated statistic was below the critical value in the  $D(n)$  table, the data were considered normal. Stated in hypothesis form:

$$H_0: KS \geq D(n)_c$$

$$H_A: KS < D(n)_c .$$

This portion of criterion test one (CT1) will be tested using the following format:

- (1) State the null and alternate hypotheses.
- (2) State the alpha level (level of significance).
- (3) State the test statistic. The test statistic for this portion of CT1 is the KS test.
- (4) State the Decision Rule. If KS is less than  $D(n)_c$ , reject  $H_0$ .

- (5) State the Decision based upon the Decision Rule.

The second criterion test (CT2), which also tests the appropriateness of the model, involves the use of the multiple coefficient of determination, known as  $R^2$ . The  $R^2$  value measures the proportion of variation in direct labor hours that is explained by the regression model.  $R^2$  is calculated by subtracting the quotient of SSE/SSTO from one. The error sum of squares, SSE, is the summation of all squared residuals, and is formally defined in statistical test one (ST1). The total sum of squares, SSTO, is calculated by summing the squared differences between each observed value of the mean of the dependent variable (11:77).

In this model,  $R^2$ , as a valid measure of explained variation, is somewhat obscured by the transformation of the model to logarithmic form.  $R^2$  in that form represents the logarithmic value of direct labor hour variation rather than variation in actual hours. Smith, in his research, developed a more meaningful statistic which he

called  $R^2$  (actual) (14:53).  $R^2$  (actual) is calculated in the same way that  $R^2$  is, except that the SSE and SSTO values are calculated after transforming the observed and predicted values of the dependent variables from the logarithmic to actual form. In that way, the variation is represented in actual hours instead of logarithms (2:31).

An appropriate model for the data would explain a high proportion of variation in direct labor, and would consequently yield a high  $R^2$  (actual). Therefore, in this criterion test, an  $R^2$  (actual) value of .75 or higher is selected as the level at which the model could not be rejected as inappropriate (2:31).

If an acceptable model is found after model acceptability testing (ST1, ST2, CT1, and CT2), predictive ability is then tested.

#### PREDICTIVE ABILITY TESTING

After the full model, with DD Form 250 data incorporated, is accepted as the result of model acceptability testing, its predictive ability is determined. This determination is made by comparing the full model with the reduced model.

To determine if the acceptable full model is a more accurate predictor than the reduced model, the full and reduced regression models are developed with the last 12

data points omitted. Then, using these models, omitted values (which were known but not used in estimating the model coefficients) are predicted. Then, an evaluation of the deviation of the predicted values from the observed values, for both the full and reduced models, is accomplished.

The comparison is made using both a statistical test (ST3) and a criterion test (CT3). The statistical test is used to determine whether the full model is significantly more accurate than the reduced model in predicting the labor hour values omitted in the prediction simulation. Where the full model may be found to be a significantly better predictor based on the statistical test, a criterion test is then applied to establish whether the improved predictive ability of the full model has a practical significance as well.

#### Statistical Test

The statistical test (ST3) is performed to determine if the average absolute deviation of the full model ( $|\bar{D}_F|$ ) is significantly less than that of the reduced model ( $|\bar{D}_R|$ ). The average absolute deviation for each model is computed by taking the absolute value of the difference between the actual and predicted direct labor hours occurring in each test situation, then separately summing

the absolute deviations for each model in all test situations (2:33).

Statistically, the null and alternate hypotheses are:

$$H_0: |\bar{D}_R| \leq |\bar{D}_F|$$

$$H_A: |\bar{D}_R| > |\bar{D}_F|$$

This hypothesis is tested using the following format:

- (1) State the null and alternate hypotheses.
- (2) State the alpha level (level of significance).
- (3) State the test statistic. The test statistic for statistical test three will be the Student's t test.
- (4) State the Decision Rule. The Decision Rule for ST3 will be to reject  $H_0$  if  $t > t_c(0.05)$ , where:

$$t = (|\bar{D}_R| - |\bar{D}_F|) / \sqrt{(S_R^2/N) + S_F^2/N}$$

- (5) State the Decision based upon the Decision Rule.

In the above Decision Rule, the variables are defined as follows:

- $S_R^2$  represents the variance of the distribution of deviations obtained with the reduced model,
- $S_F^2$  represents the variance of the distribution of deviations obtained with the full model,
- $N$  represents the number of test situations, and
- $t_c$  represents the critical t value obtained from a table of Student's t critical values (17:208-215).

### Criterion Test

Where the improved predictive ability of the full model over the reduced model may be shown to be statistically significant, the model will then be subjected to a test of practical significance. This criterion test (CT3) is necessary because (1) the reduced model, although shown to be a statistically less accurate predictor, could still be sufficiently accurate for practical application, or (2) the full model, although shown to be a statistically better predictor than the reduced model, could still be so inaccurate as to be of no value in practical application. In either instance, the addition of the acceptance rate variable would not be considered worthwhile from a cost/benefit standpoint (2:34).

To perform the criterion test (CT3), the individual deviations computed for the full and reduced models in each test situation under statistical test three (ST3) are converted into a measure of deviation expressed as a percentage of the actual direct labor hours. The use of percentage facilitates later comparison of results between this program and other programs whose values for direct labor hours are relatively large. Two categories are then established for the deviations.

These categories provide a basis for comparison of the predictive ability of the two models. When percentage deviations fall in the range greater than five percent to ten percent or less, the predictive ability is categorized as good. When percentage deviations are five percent or less, the predictive ability is categorized as excellent. The number of test situations in which the percentage deviations fall into each category is then separately summed for the full and reduced models. Totals for each category and model are then subjectively compared and the model with the greater total number of good and excellent predictions is judged to have the better practical predictive ability (2:35).

#### SUMMARY

Historical production (acceptance) data will be analyzed using least squares multiple linear regression. The research hypothesis will then be tested using the statistical and criterion tests described in this chapter.

The model's acceptability for testing is evaluated using two statistical tests and two criterion tests. If all tests are passed, the full model is then evaluated for predictive ability. The conclusion sought is that the acceptance rate is a significant factor in determining direct labor hour requirements for missile production.



The predictive ability of the model is evaluated using one statistical test and one criterion test. If both tests are passed, the full model is shown to have better practical predictive ability than the reduced model.

Certain assumptions are necessary for the regression model to be appropriate. The strength and validity of the conclusions drawn from the research hypothesis are dependent on the applicability of these assumptions. Further, the methodology contains certain limitations which must be considered. A summary of the assumptions and limitations follows.

#### Assumptions

- (1) Historical data obtained from the manufacturer were recorded accurately.
- (2) Multicollinearity did not impair the short-range predictive ability of the models.
- (3) Data measurements and transformations were accurate.
- (4) No significant loss of data precision was induced by the logarithmic transformation of the data used to facilitate multiple linear regression.
- (5) The error terms had a normal distribution with a mean of zero and constant variance, and they were statistically independent (2:41-44).

### Limitations

(1) Subjective analysis was required to assess the validity of the assumptions concerning error terms.

(2) Information derived from the data apply only to the program being studied in this research (44).

(3) Funding limitation precluded incorporating the assembly and test components into this research. This research models only the fabrication component and the total model used in the Allen/Farr research.

### CHAPTER III

#### DATA ANALYSIS AND EVALUATION

This chapter presents analysis of the efficacy of using the DD Form 250 Maverick missile acceptance data as a proxy for actual production rate. Utilizing the methodology presented in Chapter II, six regression models were tested for acceptability. The six models differ in the direct labor hour variable ( $Y_i$ ) as follows:

Model One = ( $Y_t$ ) = total direct labor hours,

Model Two = ( $Y_{tu}$ ) = unit index portion of total direct labor hours,

Model Three = ( $Y_{tsh}$ ) = standard hours portion of total direct labor hours,

Model Four = ( $Y_f$ ) = fabrication direct labor hours,

Model Five = ( $Y_{fu}$ ) = unit index portion of fabrication direct labor hours, and

Model Six = ( $Y_{fsh}$ ) = standard hours portion of fabrication direct labor hours.

Following the acceptance testing for these six models, those models found to be acceptable are tested to determine their predictive ability and then are compared with the reduced model.

## PRESENTATION OF MODELS AND ACCEPTABILITY TESTS

### Model One

Model One is presented below. The raw data and results of each statistical/criterion test are presented in Tables 4, 5, and 6.

Reduced Model:

$$Y_t = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_t) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_t = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_t) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_t$  = total direct labor hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.

### Model Two

Model Two is presented below. The raw data and results of each statistical/criterion test are presented in Tables 7, 8, and 9.

Reduced Model:

$$Y_{tu} = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_{tu}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_{tu} = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{tu}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_{tu}$  = unit index portion of total hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.

### Model Three

Model Three is presented below. The raw data and results of each statistical/criterion test are presented in Tables 10, 11, and 12.

Reduced Model:

$$Y_{tsh} = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_{tsh}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_{tsh} = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{tsh}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_{tsh}$  = standard hours portion of total direct labor hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.

#### Model Four

Model Four is presented below. The raw data and results of each statistical/criterion test are presented in Tables 13, 14, and 15.

Reduced Model:

$$Y_f = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_f) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_f = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_f) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_f$  = fabrication direct labor hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.

#### Model Five

Model Five is presented below. The raw data and results of each statistical/criterion test are presented in Tables 16, 17, and 18.

Reduced Model:

$$Y_{fu} = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_{fu}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_{fu} = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{fu}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_{fu}$  = unit index portion of fabrication direct labor hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.

### Model Six

Model Six is presented below. The raw data and results of each statistical/criterion test are presented in Tables 19, 20, and 21.

Reduced Model:

$$Y_{fsh} = B_0 \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_{fsh}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_{fsh} = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{fsh}) = \text{Log}(B_0) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

$Y_{fsh}$  = standard hours for fabrication direct labor hours/equivalent unit/accounting month,

$X_1$  = cumulative output plot point (cumulative units at end of accounting month),

$X_2$  = DD Form 250 acceptance rate/accounting month.



TABLE 4  
MODEL ONE - RAW DATA  
(Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	954.16	984.48
Estimated $B_1$	-0.24	-0.22
Estimated $B_2$	---	-0.04
<u>Data for ST1</u>		
F Ratio	765.40	409.96
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	5.25
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.26
KS Critical	---	.16
Durbin-Watson Statistic	---	1.02
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.921	.927
$R^2$ Actual	.918	.898

TABLE 5  
MODEL ONE - ST1 & ST2 RESULTS

Statistical Test One Results	
(1)	$H_0: B_1 \text{ and } B_2 = 0$ $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
(2)	$\alpha = 0.05$
(3)	Test Statistic: F-Test
(4)	Decision Rule: If the F-ratio is greater than $F^*$ , reject $H_0$ , else cannot reject $H_0$ .
(5)	Decision: F-Ratio = 409.96 $F^* = 3.15$ 409.96 is greater than 3.15, so reject $H_0$ .
Statistical Test Two Results	
(1)	$H_0: B_2 = 0$ $H_A: B_2 \neq 0$
(2)	$\alpha = 0.05$
(3)	Test Statistic: F-Test
(4)	Decision Rule: If the F Statistic is greater than $F^*$ , reject $H_0$ , else cannot reject $H_0$ .
(5)	Decision: F Statistic = 5.25 $F^* = 4.00$ 5.25 is greater than 4.00, so reject $H_0$ .

TABLE 6  
MODEL ONE - CT1 & CT2 RESULTS

---

Criterion Test One Results

---

Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.

Test of Independence of Residuals:

- (1)  $H_0$ :  $\rho$  is greater than 0  
 $H_A$ :  $\rho = 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: Durbin-Watson
- (4) Decision Rule: If  $D$  is greater than  $d_L$ , conclude  $H_A$ ; if  $D$  is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) Decision:  $D = 1.02$       1.02 is less than 1.67,  
 $d_L = 1.55$               so conclude  $H_0$ .  
 $d_U = 1.67$

Test of Normal Distribution of Residuals:

- (1)  $H_0$ :  $KS \geq D(n)_c$   
 $H_A$ :  $KS < D(n)_c$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: KS
- (4) Decision Rule: If KS is less than  $D(n)_c$ , reject  $H_0$ .
- (5) Decision:  $KS = .26$       .26 is greater than .16,  
 $D(n)_c = .16$               so cannot reject  $H_0$ .

---

Criterion Test Two Results

---

$R^2$  (Actual) = .898 and is greater than .75. So, model cannot be rejected as inappropriate for this test.

---

TABLE 7  
MODEL TWO - RAW DATA  
(Unit Index for Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	45.34	49.29
Estimated $B_1$	-0.21	-0.15
Estimated $B_2$	---	-0.11
<u>Data for ST1</u>		
F Ratio	360.54	279.32
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	31.50
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.22
KS Critical	---	.16
Durbin-Watson Statistic	---	1.22
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.845	.896
$R^2$ Actual	.878	.855

TABLE 8  
MODEL TWO - ST1 & ST2 RESULTS

---

Statistical Test One Results

---

- (1)  $H_0: B_1 \text{ and } B_2 = 0$   
 $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: F-Test
- (4) Decision Rule: If the F-ratio is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
- (5) Decision: F-Ratio = 279.32  
 $F^* = 3.15$   
 279.32 is greater than 3.15, so reject  $H_0$ .

---

Statistical Test Two Results

---

- (1)  $H_0: B_2 = 0$   
 $H_A: B_2 \neq 0$
  - (2)  $\alpha = 0.05$
  - (3) Test Statistic: F-Test
  - (4) Decision Rule: If the F Statistic is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
  - (5) Decision: F Statistic = 31.50  
 $F^* = 4.00$   
 31.50 is greater than 4.00, so reject  $H_0$ .
-

TABLE 9  
MODEL TWO - CT1 & CT2 RESULTS

Criterion Test One Results
<p>Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.</p> <p>Test of Independence of Residuals:</p> <ol style="list-style-type: none"> <li>(1) <math>H_0: \rho</math> is greater than 0 <math>H_A: \rho = 0</math></li> <li>(2) <math>\alpha = 0.05</math></li> <li>(3) Test Statistic: Durbin-Watson</li> <li>(4) Decision Rule: If D is greater than <math>d_L</math>, conclude <math>H_A</math>; if D is less than <math>d_U</math>, conclude <math>H_0</math>; if <math>d_L \leq D \leq d_U</math>, test is inconclusive.</li> <li>(5) Decision: <math>D = 1.22</math> 1.22 is less than 1.67, <math>d_L = 1.55</math> so conclude <math>H_0</math>. <math>d_U = 1.67</math></li> </ol> <p>Test of Normal Distribution of Residuals:</p> <ol style="list-style-type: none"> <li>(1) <math>H_0: KS \geq D(n)_c</math> <math>H_A: KS &lt; D(n)_c</math></li> <li>(2) <math>\alpha = 0.05</math></li> <li>(3) Test Statistic: KS</li> <li>(4) Decision Rule: If KS is less than <math>D(n)_c</math>, reject <math>H_0</math>.</li> <li>(5) Decision: KS = .22 .22 is greater than .16, <math>D(n)_c = .16</math> so cannot reject <math>H_0</math>.</li> </ol>
Criterion Test Two Results
<p><math>R^2</math> (Actual) = .855 and is greater than .75. So, model cannot be rejected as inappropriate for this test.</p>

TABLE 10  
MODEL THREE - RAW DATA  
(Standard Hours for Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	86.27	83.00
Estimated $B_1$	-0.06	-0.09
Estimated $B_2$	---	0.05
<u>Data for ST1</u>		
F Ratio	173.66	174.50
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	49.01
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.13
KS Critical	---	.16
Durbin-Watson Statistic	---	1.46
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.725	.843
$R^2$ Actual	.694	.824

TABLE 11  
MODEL THREE - ST1 & ST2 RESULTS

Statistical Test One Results	
(1)	$H_0: B_1 \text{ and } B_2 = 0$ $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
(2)	$\alpha = 0.05$
(3)	Test Statistic: F-Test
(4)	Decision Rule: If the F-ratio is greater than $F^*$ , reject $H_0$ , else cannot reject $H_0$ .
(5)	Decision: F-Ratio = 174.50 $F^* = 3.15$ 174.50 is greater than 3.15, so reject $H_0$ .
Statistical Test Two Results	
(1)	$H_0: B_2 = 0$ $H_A: B_2 \neq 0$
(2)	$\alpha = 0.05$
(3)	Test Statistic: F-Test
(4)	Decision Rule: If the F Statistic is greater than $F^*$ , reject $H_0$ , else cannot reject $H_0$ .
(5)	Decision: F Statistic = 49.01 $F^* = 4.00$ 49.01 is greater than 4.00, so reject $H_0$ .



TABLE 12  
MODEL THREE - CT1 & CT2 RESULTS

---

Criterion Test One Results

---

Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.

Test of Independence of Residuals:

- (1)  $H_0$ :  $\rho$  is greater than 0  
 $H_A$ :  $\rho = 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: Durbin-Watson
- (4) Decision Rule: If  $D$  is greater than  $d_L$ , conclude  $H_A$ ; if  $D$  is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) Decision:  $D = 1.46$  1.46 is less than 1.67,  
 $d_L = 1.55$  so conclude  $H_0$ .  
 $d_U = 1.67$

Test of Normal Distribution of Residuals:

- (1)  $H_0$ :  $KS \geq D(n)_c$   
 $H_A$ :  $KS < D(n)_c$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: KS
- (4) Decision Rule: If KS is less than  $D(n)_c$ , reject  $H_0$ .
- (5) Decision:  $KS = .13$  .13 is less than .16,  
 $D(n)_c = .16$  so reject  $H_0$ .

---

Criterion Test Two Results

---

$R^2$  (Actual) = .824 and is greater than .75. So, model cannot be rejected as inappropriate for this test.

---

TABLE 13  
MODEL FOUR - RAW DATA  
(Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	101.55	100.21
Estimated $B_1$	-0.105	-0.08
Estimated $B_2$	---	-0.04
<u>Data for ST1</u>		
F Ratio	74.82	41.78
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	4.63
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.13
KS Critical	---	.16
Durbin-Watson Statistic	---	1.34
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.531	.562
$R^2$ Actual	.530	.546

TABLE 14  
MODEL FOUR - ST1 & ST2 RESULTS.

---

Statistical Test One Results

---

- (1)  $H_0: B_1 \text{ and } B_2 = 0$   
 $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: F-Test
- (4) Decision Rule: If the F-ratio is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
- (5) Decision: F-Ratio = 41.78  
 $F^* = 3.15$   
 41.78 is greater than 3.15, so reject  $H_0$ .

---

Statistical Test Two Results

---

- (1)  $H_0: B_2 = 0$   
 $H_A: B_2 \neq 0$
  - (2)  $\alpha = 0.05$
  - (3) Test Statistic: F-Test
  - (4) Decision Rule: If the F Statistic is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
  - (5) Decision: F Statistic = 4.63  
 $F^* = 4.00$   
 4.63 is greater than 4.00, so reject  $H_0$ .
-

TABLE 15  
MODEL FOUR - CT1 & CT2 RESULTS

---

Criterion Test One Results

---

Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.

Test of Independence of Residuals:

- (1)  $H_0: \rho$  is greater than 0  
 $H_A: \rho = 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: Durbin-Watson
- (4) Decision Rule: If D is greater than  $d_L$ , conclude  $H_A$ ; if D is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) Decision: D = 1.34    1.34 is less than 1.67,  
 $d_L = 1.55$                       so conclude  $H_0$ .  
 $d_U = 1.67$

Test of Normal Distribution of Residuals:

- (1)  $H_0: KS \geq D(n)_c$   
 $H_A: KS < D(n)_c$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: KS
- (4) Decision Rule: If KS is less than  $D(n)_c$ , reject  $H_0$ .
- (5) Decision: KS = .13    .13 is less than .16,  
 $D(n)_c = .16$                       so reject  $H_0$ .

---

Criterion Test Two Results

---

$R^2$  (Actual) = .546 and is less than .75. So, model is rejected as inappropriate for this test.

---

TABLE 16  
MODEL FIVE - RAW DATA  
(Unit Index for Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	4.29	4.06
Estimated $B_1$	-0.08	-0.04
Estimated $B_2$	---	-0.07
<u>Data for ST1</u>		
F Ratio	45.02	37.61
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	18.36
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.12
KS Critical	---	.16
Durbin-Watson Statistic	---	1.81
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.406	.536
$R^2$ Actual	.450	.508

TABLE 17  
MODEL FIVE - ST1 & ST2 RESULTS

---

Statistical Test One Results

---

- (1)  $H_0: B_1 \text{ and } B_2 = 0$   
 $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: F-Test
- (4) Decision Rule: If the F-ratio is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
- (5) Decision: F-Ratio = 37.61  
 $F^* = 3.15$   
 37.61 is greater than 3.15, so reject  $H_0$ .

---

Statistical Test Two Results

---

- (1)  $H_0: B_2 = 0$   
 $H_A: B_2 \neq 0$
  - (2)  $\alpha = 0.05$
  - (3) Test Statistic: F-Test
  - (4) Decision Rule: If the F Statistic is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
  - (5) Decision: F Statistic = 18.36  
 $F^* = 4.00$   
 18.36 is greater than 4.00, so reject  $H_0$ .
-

TABLE 18  
MODEL FIVE - CT1 & CT2 RESULTS

---

Criterion Test One Results

---

Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.

Test of Independence of Residuals:

- (1)  $H_0$ :  $\rho$  is greater than 0  
 $H_A$ :  $\rho = 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: Durbin-Watson
- (4) Decision Rule: If  $D$  is greater than  $d_L$ , conclude  $H_A$ ; if  $D$  is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) Decision:  $D = 1.81$      $1.81$  is greater than  $1.55$ ,  
 $d_L = 1.55$                       so conclude  $H_A$ .  
 $d_U = 1.67$

Test of Normal Distribution of Residuals:

- (1)  $H_0$ :  $KS \geq D(n)_c$   
 $H_A$ :  $KS < D(n)_c$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: KS
- (4) Decision Rule: If KS is less than  $D(n)_c$ , reject  $H_0$ .
- (5) Decision:  $KS = .12$      $.12$  is less than  $.16$ ,  
 $D(n)_c = .16$                       so reject  $H_0$ .

---

Criterion Test Two Results

---

$R^2$  (Actual) = .508 and is less than .75. So, model is rejected as inappropriate for this test.

---

TABLE 19  
MODEL SIX - RAW DATA  
(Standard Hours for Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated $B_0$	25.75	26.76
Estimated $B_1$	-0.03	-0.06
Estimated $B_2$	---	0.05
<u>Data for ST1</u>		
F Ratio	8.99	13.41
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	15.82
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.15
KS Critical	---	.16
Durbin-Watson Statistic	---	1.97
Durbin-Watson Critical ( $d_U/d_L$ )	---	1.67/1.55
<u>Data for CT2</u>		
$R^2$ Log	.120	.292
$R^2$ Actual	.111	.268



TABLE 20  
MODEL SIX - ST1 & ST2 RESULTS

---

Statistical Test One Results

---

- (1)  $H_0: B_1 \text{ and } B_2 = 0$   
 $H_A: B_1 \neq 0 \text{ and/or } B_2 \neq 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: F-Test
- (4) Decision Rule: If the F-ratio is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
- (5) Decision: F-Ratio = 13.41  
 $F^* = 3.15$   
 13.41 is greater than 3.15, so reject  $H_0$ .

---

Statistical Test Two Results

---

- (1)  $H_0: B_2 = 0$   
 $H_A: B_2 \neq 0$
  - (2)  $\alpha = 0.05$
  - (3) Test Statistic: F-Test
  - (4) Decision Rule: If the F Statistic is greater than  $F^*$ , reject  $H_0$ , else cannot reject  $H_0$ .
  - (5) Decision: F Statistic = 15.82  
 $F^* = 4.00$   
 15.82 is greater than 4.00, so reject  $H_0$ .
-

TABLE 21

## MODEL SIX - CT1 &amp; CT2 RESULTS

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 Criterion Test One Results
 

---

Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.

Test of Independence of Residuals:

- (1)  $H_0$ :  $\rho$  is greater than 0  
 $H_A$ :  $\rho = 0$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: Durbin-Watson
- (4) Decision Rule: If  $D$  is greater than  $d_L$ , conclude  $H_A$ ; if  $D$  is less than  $d_U$ , conclude  $H_0$ ; if  $d_L \leq D \leq d_U$ , test is inconclusive.
- (5) Decision:  $D = 1.97$      $1.97$  is greater than  $1.55$ ,  
 $d_L = 1.55$                       so conclude  $H_A$ .  
 $d_U = 1.67$

Test of Normal Distribution of Residuals:

- (1)  $H_0$ :  $KS \geq D(n)_c$   
 $H_A$ :  $KS < D(n)_c$
- (2)  $\alpha = 0.05$
- (3) Test Statistic: KS
- (4) Decision Rule: If KS is less than  $D(n)_c$ , reject  $H_0$ .
- (5) Decision:  $KS = .15$      $.15$  is less than  $.16$ ,  
 $D(n)_c = .16$                       so reject  $H_0$ .

---

 Criterion Test Two Results
 

---

$R^2$  (Actual) = .268 and is less than .75. So, model is rejected as inappropriate for this test.

---

### SUMMARY OF MODEL ACCEPTABILITY TEST RESULTS

Each of the six models described earlier was subjected to two statistical tests and two criterion tests to evaluate their overall acceptability as suitable models for further predictive ability testing. Below is a concise summary of each model's score (pass/fail) for each of the statistical and criterion tests presented in the previous section. It is important to remember that a model must pass all four of these tests in order to be found acceptable for further predictive ability testing.

#### Model One

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus confirms the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus,  $H_0$  was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Failed. The calculated KS Statistic was greater than the critical value listed in the table. Thus, the data were not considered to be normally distributed.

Criterion Test Two (CT2). Passed. The  $R^2$  (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model One passed ST1, ST2, and CT2. It failed all tests contained in CT1 and is, therefore, not acceptable for further testing.

#### Model Two

Statistical Test One (ST1). Passed. The F-ratio is greater than F critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus,  $H_0$  was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Failed. The calculated KS Statistic was greater than the critical value listed in the table. Thus, the data was not considered to be normally distributed.

Criterion Test Two (CT2). Passed. The  $R^2$  (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model Two reacted identically to Model One. Model Two passed ST1, ST2, and CT2. It failed all tests contained in CT1 and is, therefore, not acceptable for further testing.

### Model Three

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data is added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus,  $H_0$  was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data is considered to be normally distributed.

Criterion Test Two (CT2). Passed. The  $R^2$  (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model Three came very close to passing all four tests. Model Three passed all tests except the Test of Independence of Residuals in CT1. This failure was marginal but was enough to deem Model Three unacceptable for further testing.

#### Model Four

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus,  $H_0$  was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data are considered to be normally distributed.

Criterion Test Two (CT2). Failed. The  $R^2$  (Actual) was less than .75. Thus, the model does not explain the variation in direct labor hours during the regression

analysis.

In summary, Model Four passed ST1, ST2 and failed CT1 and CT2. Therefore, Model Four is not acceptable for further testing.

#### Model Five

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall pass.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Passed. The calculated Durbin-Watson Statistic is greater than the lower limit of the table value. Thus,  $H_A$  was concluded which indicates the residuals are independent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value



listed in the table. Thus, the data were considered to be normally distributed.

Criterion Test Two (CT2). Failed. The  $R^2$  (Actual) is less than .75. Thus, the model does not explain the variation in direct labor hours during the regression analysis.

In summary, Model Five came very close to being acceptable for further testing. All tests were passed except for CT2. Thus, the model is not acceptable for further testing.

#### Model Six

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall pass.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Passed. The calculated Durbin-Watson Statistic is greater than the

lower limit of the table value. Thus,  $H_A$  was concluded which indicates the residuals are independent.

c. Test of normal distribution of residuals. Passed.

The calculated KS Statistic was less than the critical value listed in the table. Thus, the data were considered to be normally distributed.

Criterion Test Two (CT2). Failed. The  $R^2$  (Actual) is less than .75. Thus, the model does not explain the variation in direct labor hours during the regression analysis.

In summary, Model Six is identical to Model Five. All tests were passed except for CT2 and the model is not acceptable for further testing.

For ease of comparison, Table 22 further condenses the results of the acceptability testing.

#### SUMMARY OF RESEARCH HYPOTHESIS ANALYSIS

The research hypothesis stated that the predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

In the Allen/Farr research effort, it was concluded that the addition of the production rate variable explained a significant amount of variation in direct labor hours. Additionally, Allen/Farr concluded that the addition of the production rate variable (full model) further enhanced the basic model's (reduced model's)

TABLE 22  
SUMMARY OF MODEL  
ACCEPTABILITY TEST RESULTS

MODEL NUMBER	TEST CATEGORY			
	ST1	ST2	CT1	CT2
1	Pass	Pass	Fail	Pass
2	Pass	Pass	Fail	Pass
3	Pass	Pass	Fail	Pass
4	Pass	Pass	Fail	Fail
5	Pass	Pass	Pass	Fail
6	Pass	Pass	Pass	Fail

predictive ability.

This research effort substituted the DD Form 250 acceptance rate for the production rate variable in the Allen/Farr data and concluded very definite results. Not one of the six models tested with this proxy were found acceptable for further predictive ability testing. Because Allen/Farr experienced satisfactory results with their models, it can only be concluded that acceptance rate in no way correlates with actual production rate for the Maverick missile data and is not a reliable proxy for actual production rate data.

Both of the statistical tests (ST1 and ST2) indicated full support for the research hypothesis in all six cases. The criterion tests (CT1 and CT2), however, produced mixed results.

Referring to Table 22, it is interesting to note that whenever Models One, Two, or Three failed CT1, these same models passed CT2. Model Four failed both CT1 and CT2. Equally interesting is that Models Five and Six passed CT1 but failed CT2. These comparisons, together with all models passing ST1 and ST2, comprise the only noticeable patterns in the test results.

The results of testing for Statistical Test One (ST1) in every model demonstrated that the explanatory power added by the acceptance rate data was

statistically significant at the 0.05 level of significance. Notwithstanding these excellent results, all of the models either failed the KS test for normality of residuals, the Durbin-Watson test for independence of residuals, the constant variance test, or a combination of these tests.

In summary, the results did not support the research hypothesis for the Maverick data used by Allen/Farr. In fact, the models were not even acceptable for further predictive ability testing. Chapter IV will contain the summary, conclusions, and recommendations for these research results.

## CHAPTER IV

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The years following World War II have presented an era of increasing complexity in DOD weapon systems acquisitions. Air Force managers attempting to plan the acquisition, operation, and maintenance of major weapon systems face an increasing array of obstacles in the form of inflation, spiraling cost of energy, and international political instability. While the task has become more difficult, the need for more accurate cost estimating has become more obvious.

Direct labor is one of the most significant cost elements in a major system acquisition and experience has shown that direct labor costs are most often estimated using learning curve analysis.

### SUMMARY

#### Literature Review

Learning curve models were in use as early as the 1920s and even more interest was generated as a result of the aerospace industry's experience during World War II. Over the years, numerous variations of the basic learning curve model have been investigated. Since the DOD is constantly faced with budgetary and political controls that

cause program accelerations and decelerations, the variation that has the most promise for DOD application is the model that considers the effect of production rate variations.

It is possible, however, that this production rate variable is not always accessible or even available to the DOD researcher interested in projecting the costs of a future DOD major weapons system. When these data are not available, a proxy must be developed as a substitute for the production rate variable. This research effort has investigated the use of acceptance rate as a reliable proxy for the production rate variable in the attempt to predict direct labor costs for the acquisition of a major weapon system.

Most of the research on the effect of production rate changes concluded that production rate is a significant determinant of direct labor costs. Smith developed a learning curve model that included a production rate variable, tested the model on airframe production programs and concluded that the model yielded promising results. Smith's model has been applied to other airframe programs, avionics, and engines, and now has been extended to air-launched missiles in the form of the acceptance rate proxy.

### The Model

The production rate model, which Smith called the full model, is presented as follows:

$$Y = B_0 \cdot X_1^{B_1} \cdot X_2^{B_2} \cdot 10^e$$

where the variables are described as follows:

- Y represents direct labor hours,
- X<sub>1</sub> represents cumulative output,
- X<sub>2</sub> represents the production rate (acceptance rate in this research),
- e represents the variation which remains unexplained by the variables in the model, and

B<sub>0</sub>, B<sub>1</sub>, and B<sub>2</sub> are regression coefficients.

To facilitate regression analysis, the model is linearized using logarithms as follows:

$$\text{Log } Y = \text{Log } B_0 + B_1 \text{ Log } X_1 + B_2 \text{ Log } X_2 + e$$

The reduced model is identical to the full model except that the reduced model does not include the production rate variable (2:98).

### Research Objective

As stated in Chapter I, the objective of this research was to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.



### Methodology

Linear regression analysis of the logarithmic forms of the full and reduced models was employed to achieve the research objective. Data were obtained from the Maverick missile production program and the treatment of these data is described in Chapter II. Testing of the research hypothesis first required determining if the model, using the DD Form 250 acceptance rate data, is acceptable. Then, if the model had been found to be acceptable, the predictive ability of the model would have been compared to the predictive ability of the model using actual production rate data to determine if any compromise exists.

To determine if a model using the DD Form 250 acceptance data is acceptable required two steps. The first step examined the statistical significance of the model's regression coefficients by regression analysis of historical production data. This step was composed of two statistical steps. The second step involved the use of two criterion tests to evaluate the appropriateness of the model for this data. The dependent variable of the full model, in log-linear form, was subjected to regression analysis. The independent variables were the logarithms of cumulative output and the DD Form 250 acceptance rate.

After the full model, with the DD Form 250 rate incorporated, is accepted as the result of model

acceptability testing, its predictive ability can be determined. This determination is made by comparing the full model with the reduced model.

To determine if the acceptable full model is a more accurate predictor than the reduced model, the full and reduced regression models were developed with the last 12 data points omitted. Then, using these models, omitted values would be predicted. Then, an evaluation of the deviation of the predicted values from the observed values, for both the full and reduced models, would have been accomplished.

Had the models been found to be acceptable for further predictive ability testing, the comparison would have been made using both a statistical test and a criterion test. The statistical test is used to determine whether the full model is significantly more accurate than the reduced model in predicting the labor hour values omitted in the prediction simulation. Where the full model is found to be a significantly better predictor based on the statistical test, a criterion test is then applied to establish whether the improved predictive ability of the full model has a practical significance as well.

AD-A135 480

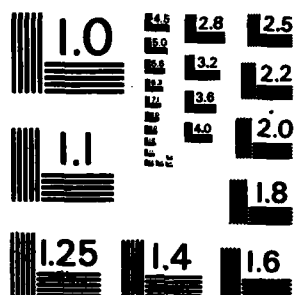
THE EFFECT OF SUBSTITUTING THE DD FORM 250 ACCEPTANCE  
RATE FOR ACTUAL PRO... (U) AIR FORCE INST OF TECH  
WRIGHT-PATTERSON AFB OH SCHOOL OF SYST... G D GENTRY  
SEP 83 AFIT-LSSR-97-83 F/G 14/1

2/2

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1 84  
DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

## CONCLUSIONS

This research provides three primary conclusions. First, the production rate, as substituted by the DD Form 250 acceptance rate, failed to explain a significant amount of variation in direct labor hours in the six models examined. Of the six models, none produced acceptable results using the acceptance rate proxy. There was no evident support to conclude that the DD Form 250 acceptance rate variable should be considered as a reliable proxy for actual production rate when evaluating missile production programs.

Second, the results of the predictive ability comparisons were not able to be tested because the model acceptability tests were failed in all six cases. Thus, the DD Form 250 acceptance data, as a proxy, proved to be unreliable as a substitute for actual production data in the prediction of direct labor costs.

Third, as a result of hypotheses testing, it is concluded that Smith's model has no potential for missile production programs when using the DD Form 250 acceptance rate as a proxy for actual production rate. This conclusion is based solely on this research and in no way infers that other proxies, such as delivery rate data, should not be investigated.

## RECOMMENDATIONS

This type of learning curve analysis has potential application anywhere that learning curve theory applies and should be used widely within DOD to test the effects of any moderating variable on the cost of a major weapon system acquisition.

A related recommendation is that the research applied in this effort be conducted on delivery rate as well as acceptance rate for other production programs within the DOD. The ease of obtaining these data, compared with the difficulty of obtaining actual production data in some cases, makes the use of proxies an attractive alternative for DOD researchers interested in predicting the direct labor costs of major acquisition.

Finally, it is important to reiterate the Allen/Farr recommendation that a checklist guide to the practical use of Smith's model be developed. Such a guide would encourage the use of the model by those who are uneasy with statistics and the seeming complexity of the model (2:103).

**APPENDIX**  
**THE COMPUTER PROGRAM PRODRATE**

The revised version of PRODRATE developed for this research significantly reduced user costs and increased program usability. PRODRATE users can now perform essential residual analysis with the additional PRODRATE statistics and the statistical packages already incorporated in the basic computer program. In addition, several options are now available to drastically decrease run-time and increase the usability of the prediction routines.

This section lists the computer program PRODRATE in its entirety. The original program was developed by Colonel Larry L. Smith, and later modified by Captain David Y. Stevens, Captain Scott C. Allen, and Captain Charles M. Farr. The version listed incorporates the original program and all modifications. The actual program used during this research is the program presented in this section.





```

6180 * REGRESSION IS THEN PERFORMED AS FOLLOWS: Y REGRESSED ON X1, Y REGRESSED ON X2, AND",//
6190 * FINALLY Y REGRESSED ON BOTH X1 AND X2. OBSERVED DIRECT LABOR REQUIREMENTS, PREDICTED",//
6200 * DIRECT LABOR REQUIREMENTS, AND RESIDUALS ARE PRINTED IN ORIGINAL (UNTRANSFORMED) FORM FOR",//
6300 * EACH REGRESSION SITUATION. IN ADDITION, SUMMARY STATISTICS ARE PRINTED FOR EACH MODEL. THE",//
6400 * SUMMARY STATISTICS INCLUDE TWO COEFFICIENTS OF DETERMINATION R SQUARED LOG AND R SQUARED",//
6500 * ACTUAL. THE R SQUARED LOG REPRESENTS THE GOODNESS OF FIT OF THE MODEL TO THE TRANSFORMED",//
6600 * DATA (LOG FORM). THE R SQUARED ACTUAL, ON THE OTHER HAND, IS COMPUTED USING THE",//
6700 * UNTRANSFORMED RESIDUALS, AND IS REPRESENTATIVE OF HOW WELL THE MODEL FITS THE UNTRANSFORMED",//
6800 * DATA. THE DURBIN-WATSON STATISTIC IS CALCULATED FOR ASSESSMENT OF AUTOCORRELATION",//
6900 * OF THE RESIDUALS.")
6910 & FORMAT(I11,12,)//
7000 * SEVERAL OPTIONS ARE AVAILABLE WITHIN THIS PROGRAM AND CAN BE SELECTED BY APPROPRIATE",//
7100 * ANSWERS TO THE FOLLOWING QUESTIONS:",//
7200 * 1. DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE ..... AND CONVERTED TO",//
7300 * LOGARITHMS?",//
7400 * YES - WILL CAUSE THE PRINTING OF A LISTING OF THE RATIONAL INPUT DATA AND THE",//
7500 * ASSOCIATED LOGARITHMIC VALUES.",//
7600 * NO - SUPPRESSES THIS OPTION.",//
7700 * 2. COMPLETE PRINTOUT?",//
7800 * YES - WILL CAUSE OUTPUT TO BE PRINTED IN FULL FORMAT AS DESCRIBED ABOVE.",//
7900 * NO - WILL DELETE THE LISTING OF OBSERVED, PREDICTED, AND RESIDUAL VALUES",//
8000 * BETWEEN TABLES OF SUMMARY STATISTICS. IT WILL ALSO DELETE LISTING OF",//
8100 * INDIVIDUAL MATRICES FOR THE SHORTRANGE PREDICTIVE ABILITY OPTION(I.E.",//
8200 * ONLY THE SUMMARY TABLE WILL BE LISTED.",//
8300 * 3. DO YOU WANT A COMPARISON OF THE SHORTRANGE PREDICTIVE ABILITY OF THE TWO MODELS?",//
8400 * YES - WILL CAUSE THE PREDICTIVE ABILITY TEST OPTION TO BE ACTIVATED AND THE USER WILL",//
8500 * BE TOLD: 'ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES)'.",//
8600 * THE USER SHOULD ENTER THE NUMBER OF THE FIRST CASE TO BE PREDICTED FOLLOWED",//
8700 * BY THE LAST CASE TO BE PREDICTED, SEPARATED BY A COMMA. THE CASE NUMBERS",//
8800 * MUST BE INTEGER VALUES GREATER THAN OR EQUAL TO 2. THE PREDICTIVE",//
8900 * ABILITY TEST SIMULATES FUTURE PREDICTIONS BY PERFORMING A STEPWISE TRUNCATION OF",//
9000 * THE HISTORICAL DATA. FOR THIS REASON, AN UPPER LIMITATION ON THE NUMBER OF",//
9100 * CASES TRUNCATED WOULD BE: ((TOTAL NUMBER OF CASES IN DATA FILE) / 2) - 2",//
9200 * FOR EXAMPLE, IF YOUR DATA FILE CONTAINS 50 CASES, YOUR UPPER LIMIT WOULD BE",//
9300 * 23 CASES. THIS, OF COURSE, REPRESENTS ONLY THE MAXIMUM NUMBER OF CASES THAT",//
9400 * COULD BE TRUNCATED. IN PRACTICE YOU MAY WANT TO TRUNCATE ONLY A SMALL NUMBER OF",//
9500 * CASES. THUS, IF YOUR DATA IS COLLECTED IN MONTHLY INTERVALS, YOU CAN LOOK AT",//
9600 * THE PREDICTIVE ABILITY OF THE FULL AND REDUCED MODELS FOR AN 18 MONTH TIME SPAN BY",//
9700 * SPECIFYING AN 18 CASE RANGE. IF YOUR DATA IS COLLECTED IN QUARTERS, YOU CAN LOOK",//
9800 * AT THE PREDICTIVE ABILITY OF BOTH MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING",//
9900 * '6'. AFTER ALL PREDICTIVE ABILITY TEST SITUATIONS ARE PRINTED, THE PROGRAM",//
10000 * PRINTS A SUMMARY OF THE TEST RESULTS.",//
10100 * NO - SUPPRESSES THIS OPTION.",//
10200 * 4. DO YOU WANT PROJECTION AND SENSITIVITY MATRIX?",//
10300 * YES - WILL CAUSE PRINTING OF PROJECTION AND SENSITIVITY MATRIX. THIS MATRIX PRESENTS",//
10400 * PROJECTED DIRECT LABOR REQUIREMENTS FOR SELECTED PAIRS OF CUMULATIVE PRODUCTION",//
10500 * PLOT POINTS AND PRODUCTION RATES. THE PROJECTION INTERVAL FOR THE CUMULATIVE",//
10600 * PRODUCTION PLOT POINT IS 12 OF THE LAST OBSERVED VALUE. THE PROJECTION VALUES",//
10700 * FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF",//
10800 * THE LAST OBSERVED VALUE OF PRODUCTION RATE.",//
10900 * NO - SUPPRESSES THIS OPTION.",//
11000 * ***SPECIAL NOTE*** THE PREDICTED DIRECT LABOR REQUIREMENTS AND RESIDUALS FOR EACH MODEL",//

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16130 * ARE STORED IN SEPARATE FILES. THE VALUES FOR THE STANDARD LEARNING CURVE MODEL ARE",/,
16135 * STORED IN A FILE CALLED 'STDLEARN'; THE VALUES FOR THE PRODUCTION RATE VARIABLE ALONE",/,
16140 * MODEL IN THE FILE 'REDHOURS'; AND THE VALUES FOR THE COMBINED CUM. PRODUCTION AND",/,
16150 * PRODUCTION RATE MODEL IN THE FILE 'FULLMODL'. USERS MAY ACCESS THESE FILES FOR ",/,
16160 * RESIDUAL ANALYSIS BY OTHER COPPER IMPACT STATISTICAL PROGRAMS, IF DESIRED.")
16200
16300
16400
16500 DIMENSIONING VARIABLES
16600
16700 ALPHA ANSWER(10),ANS(10)
16800 FILENAME DATAFILE
16900 DIMENSION PLOT(150),RATE(150),HRS(150),T(150),Z1(150),Z2(150),LN(150),
17000 KENPLOT(150),PRORATE(15),FHRS(150,15),ADEVR(999),ADEVF(999),RESID(200)
17100
17200 DATA SUMMS,SUMX1,SUMX2,SUMY,SSY1,SSY2,SUMX1Y,SUMX2Y,SSX1X2,
17300 SSE,SSE1,SSE2,SSEL,SSEL1,SSEL2,SST0,SST01,SST02,SSTOL,SSTOL1,SSTOL2/21*9/
17400
17500
17600
17700
17800 PART I - BEGIN PROGRAM, INSTRUCTIONS, DATA INPUT, DATA TRANSFORMATION, AND OPTION SELECTIONS.
17900
18000
18100 PRINT 1195
18200 1195 FORMAT(11" THE CUMULATIVE PRODUCTION AND PRODUCTION RATE COST MODEL")
18300
18400 INSTRUCTIONS OPTION SELECTION
18500
18600
18700 OPTION NOWARN
18800 OPEN(FILE='LOGFILE',UNIT=4,ACCESS='LINEAR',STATUS='UNKNOWN')
18900 OPEN(FILE='STDCURVE')
19000 OPEN(FILE='REDCURVE')
19100 OPEN(FILE='FULCURVE')
19200 OPEN(FILE='STDLEARN')
19300 OPEN(FILE='REDHOURS')
19400 OPEN(FILE='FULLMODL')
19500 CLOSE(FILE='STDCURVE')
19600 CLOSE(FILE='REDCURVE')
19700 CLOSE(FILE='FULCURVE')
19800 PRINT 10
19900 10 FORMAT(10"DO YOU WANT INSTRUCTIONS")
20000 100 INPUT, ANSWER(1)
20100 IF (ANSWER(1).EQ."NO") GO TO 102
20200 IF (ANSWER(1).EQ."YES") GO TO 101
20300 PRINT," ANSWER YES OR NO ONLY PLEASE"
20400 PRINT," "
20500 GO TO 100
20600
20700 101 PRINT 5
20800 PRINT 6
20900 102 PRINT,"COMPLETE PRINTOUT"
21000 INPUT,ANS(3)
21100 IF (ANS(3).EQ."NO".OR.ANS(3).EQ."YES")GO TO 672
21200 PRINT,"ANSWER YES OR NO ONLY PLEASE"
21300 GO TO 102

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1490C.....
1540C INPUT THE DATA AND TRANSFORM THE VARIABLES TO LOGARITHMS
1510C.....
1520C
1530 672 PRINT 20
1540 20 FORMAT(1X,"PLEASE ENTER THE NAME OF YOUR DATA FILE")
1550 INPUT, DATAFILE
1560 READ(DATAFILE,*)LN(1),NCASES
1570 DO 30 I=1,NCASES
1580 READ(DATAFILE,*)LN(I),HRS(I),PLOT(I),RATE(I)
1590 Y(I) = ALOC10(HRS(I))
1600 X1(I) = ALOC10(PLOT(I))
1610 X2(I) = ALOC10(RATE(I))
1620 WRITE(4,26)I,Y(I),X1(I),X2(I)
1630 26 FORMAT (1X,I2,2X,F9.7,2X,F9.7,2X,F9.7)
1640 SUMHRS = SUMHRS + HRS(I)
1650 SUMX1 = SUMX1 + X1(I)
1660 SUMX2 = SUMX2 + X2(I)
1670 SUMY = SUMY + Y(I)
1680 SSX1 = SSX1 + X1(I)**2
1690 SSX2 = SSX2 + X2(I)**2
1700 SSY = SSY + Y(I)**2
1710 SUMX1Y = SUMX1Y + X1(I)*Y(I)
1720 SUMX2Y = SUMX2Y + X2(I)*Y(I)
1730 SUMX1X2 = SUMX1X2 + X1(I)*X2(I)
1740 30CONTINUE
1750C.....
1760C DATA CHECK OPTION SELECTION
1770C.....
1780 PRINT 35,DATAFILE
1790 35 FORMAT(1X,"DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE ",A0," AND CONVERTED TO LOGARITHMS")
1800 103 INPUT,ANSWER(2)
1810 IF (ANSWER(2).EQ."NO") GO TO 104
1820 IF (ANSWER(2).EQ."YES") GO TO 104
1830 PRINT," ANSWER YES OR NO ONLY PLEASE"
1840 GO TO 103
1850C.....
1860C PREDICTIVE ABILITY TEST OPTION SELECTION
1870C.....
1880 104 PRINT 40
1890 40 FORMAT(1X,"DO YOU WANT A COMPARISON OF THE SHORTRANCE PREDICTIVE ABILITY OF THE TWO MODELS")
1900 105 INPUT,ANSWER(3)
1910 IF (ANSWER(3).EQ."NO") GO TO 106
1920 IF (ANSWER(3).EQ."YES") GO TO 203
1930 PRINT," ANSWER YES OR NO ONLY PLEASE"
1940 GO TO 105
1950 203 PRINT 42
1960 42 FORMAT(1X,"ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES)")
1970 1900 INPUT,I1TRUNC,I10END
1980 IF(NCASES-I1TRUNC+1.LE.NCASES/2-2)GO TO 106
1990 PRINT 1004
2000 1004 FORMAT(1X,"NUMBER OF CASES INPUT EXCEED ALLOWABLE AMOUNT--REENTER NUMBER OF CASES TO BE TRUNCATED")
2010 GO TO 1900

```

```

2050C:.....
2060C PROJECTION AND SENSITIVITY MATRIX OPTION SELECTION
2070C:.....
2080 106 PRINT 45
2090 45 FORMAT(11,"DO YOU WANT PROJECTION AND SENSITIVITY MATRIX")
2100 107 INPUT,ANSWER(4)
2110 IF (ANSWER(4).EQ."NO") GO TO 108
2120 IF (ANSWER(4).EQ."YES") GO TO 108
2130 PRINT," ANSWER YES OR NO ONLY PLEASE"
2140 GO TO 107
2150C:.....
2160C BEGIN DATA CHECK OPTION
2170C:.....
2180 108 IF (ANSWER(2).EQ."NO") GO TO 109
2190 PRINT 50,DATAFILE
2200 50 FORMAT(11,1,75(" "),1,51,"INPUT DATA AS READ FROM FILE ",A8," AND CONVERTED TO LOGARITHMS",
2210 1,75(" "))
2220 PRINT," LINE DIRECT LABOR HOURS * CUM PROD PLOT POINT * PRODUCTION RATE"
2230 PRINT," NUMBER RATIONAL LOGARITHM * RATIONAL LOGARITHM * RATIONAL LOGARITHM"
2240 DO 40 1=1,NCASES
2250 PRINT 55,LN(1),HRS(1),T(1),PLOT(1),X1(1),RATE(1),X2(1)
2260 55 FORMAT(11,1,13,51,F8.2,2X,F9.7," * ",F8.2,2X,F9.7," * ",F8.2,2X,F9.7)
2270 60CONTINUE
2280 PRINT 45
2290 45 FORMAT (11,75(" "))
2300 109 CONTINUE
2310C:.....
2320C
2330C PART II - PEARSON CORRELATION COEFFICIENTS AND REGRESSION ANALYSIS
2340C
2350C:.....
2360C:.....
2370C CALCULATE AND PRINT PEARSON CORRELATION COEFFICIENTS
2380C:.....
2390 RX1Y = (SUMX1Y-SUMX1*SUMY/NCASES)/SQRT((SSX1-(SUMX1**2/NCASES))*(SSY-(SUMY**2/NCASES)))
2400 RX2Y = (SUMX2Y-SUMX2*SUMY/NCASES)/SQRT((SSX2-(SUMX2**2/NCASES))*(SSY-(SUMY**2/NCASES)))
2410 PX1Z = (SUMX1Z-SUMX1*SUMZ/NCASES)/SQRT((SSX1-(SUMX1**2/NCASES))*(SSZ-(SUMZ**2/NCASES)))
2420 RX1X = 1.0
2430 RX2X = 1.0
2440 RYY = 1.0
2450 PRINT 71,RYY,RX1Y,RX2Y,R1Y,RX1X,RX2X,R1Y,RX1Z,RX2Z,R1Z,RX1Z,RX2Z
2460 71 FORMAT(11,1,1,45(" "),1,41,"PEARSON CORRELATION COEFFICIENTS ",
2470 "MATRIX",1,1,45(" "),1,61," ",51,"Y",61," ",51,"X1",51," ",51,
2480 "X2",1,1,45(" "),1,21,"Y",31,3(" ",F10.7,1X),1,11,45(" "),1,21,
2490 "X1",21,3(" ",F10.7,1X),1,1,45(" "),1,21,"X2",21,3(" ",F10.7,1X),1,11)
2500C:.....
2510C CALCULATE AND PRINT THE REGRESSION RESULTS OF THE STANDARD LEARNING CURVE MODEL
2520C:.....
2530 B1 = (SUMX1Y-(SUMX1*SUMY/NCASES))/(SSX1-(SUMX1**2/NCASES))
2540 YBAR = SUMY/NCASES
2550 HRSBAR = SUMHRS/NCASES
2560 X1BAR = SUMX1/NCASES

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2576      X2BAR = SUMX2/NCASES
2580      SS = YEAR- 81*X2BAR
2590      A20 = 10.000
2600 IF (ANS(3).EQ."N")PRINT 775
2610 775 FORMAT(//1X,75(" ")//14X,"RESULTS OF STANDARD LEARNING CURVE MODEL")
2620 IF (ANS(3).EQ."NO")GO TO 776
2630 PRINT 75
2640 75 FORMAT(1X,75(" ")//14X,"RESULTS OF THE STANDARD LEARNING",
2650 " CURVE MODEL",//1X,75(" ")//1X,"CASE",3X,"OBSERVED",5X,"PREDICTED",
2660 5X,"RESIDUAL",5X,"% DEVIATION")
2670 776 DO 110 I=1,NCASES
2680      YHATL = B0 + B1 * X1(I)
2690      RESIDL = Y(I) - YHATL
2700      SSE1 = SSE1 + RESIDL ** 2
2710      SSTOL1 = SSTOL1 + (Y(I) - YBAR) ** 2
2720      THAT = 10 ** YHATL
2730      RESID(I) = RESIDL - THAT
2740      PERCENT = (RESID(I) / RESID(I) + 100)
2750      SSE1 = SSE1 + RESID(I) ** 2
2760      SSTO1 = SSTO1 + (RESID(I) - RESBAR) ** 2
2770 WRITE('STDLEARN',20)THAT,RESID(I)
2780 20 FORMAT(F8.2,F8.2)
2790 IF (ANS(3).EQ."NO")GO TO 110
2800 PRINT 80,1,RES(I),THAT,RESID(I),PERCENT
2810 80 FORMAT(1X,10,4X,F8.2,6X,F8.2,5X,F8.2,7X,F6.2)
2820 110 CONTINUE
2830 CLOSE(FILE='STDLEARN')
2840 CALL SYSTEN('/SORT+++ STDLEARN:STDCURVE:ZRO1-1,-2',02000)
2850 DO 2770 I=1,NC
2860 READ('STDCURVE',*)THAT,RESID(I)
2870 SUMRESID=SUMRESID+RESID(I)**2
2880 IF(I.CT.1)
2890 RESIDIF=RESID(I)-RESID(I-1)
2900 RESIDIF2=RESIDIF**2
2910 RESIDSUM=RESIDSUM+RESIDIF2
2920 ENDOF
2930 2770 CONTINUE
2940 DUCTAT=RESIDSUM/SUMRESID
2950 SUMRESID=RESIDSUM
2960 *****
2970C CALCULATE AND PRINT STATISTICS FOR THE STANDARD LEARNING CURVE MODEL
2980C *****
2990 2000 NMF=NCASES-2
3000      THSEL = (SSTOL1 - SSE1)
3010      THSEL = SSE1 / NMF
3020      SEE = SORT (THSEL)
3030      WARD = SEE / (1 / NCASES + X2BAR ** 2 / (SEE1 - (SUMX1 ** 2 / NCASES)))
3040      SED = SORT (WARD)
3050      SED1 = SEE / (SORT(SEE1-(SUMX1**2/NCASES)))
3060      RSOL1 = (SSTOL1 - SSE1) / SSTOL1
3070      RSOL1 = (SSTO1 - SSE1) / SSTO1
3080      FSTAT10= THSEL / THSEL
3090      PLEARN= 110 ** (D1 + LOG10(2.0)) + 100

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3100 PRINT B1,BP,SEB,ABP,B1,SEB1,RSGL1,SEE,TMSL,TMSL1,FRATIO,NDFO,RSOAI,PLEARN,DNSTAT
3110 .. 81 FORMAT(11,75(" "),/11,"THE EQUATION FOR THIS MODEL IS: ",
3120 " THAT = B0 + X1 ** B1",/11,
3130 "IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1)",
3140 /11,"WHERE: LOG(B0) =",F8.5,41,"STD ERROR =",F8.5,41,"B0 =",F11.5,
3150 /11,"B1 =",F8.5,41,"STD ERROR =",F8.5,
3160 /11,"SUMMARY STATISTICS:",/11,
3170 "R SQUARED LOG =",F7.5,141,"STD ERROR EST =",F11.1,11,
3180 "MSE",131,"=",F9.5,81,"MSR",111,"=",F9.5,11,
3190 "F RATIO",91,"=",F9.4,81,"D. F. (N/D) = 1/",13,11,
3200 "R SQUARED ACTUAL =",F7.5,81,"LEARNING FACTOR =",F9.5," PERCENT",
3210 /11,"DURBIN-WATSON STATISTIC =",F9.6
3220 /11,75(" ")
3230 .....
3240 CALCULATE AND PRINT THE REGRESSION RESULTS FOR THE REDUCED HRS VS RATE MODEL
3250 .....
3260 B2 = (SUMX2 - ((SUMX2 * SUMY) / NCASES)) / (SSX2 - (SUMX2 ** 2 / NCASES))
3270 B0 = YBAR - B2 * X2BAR
3280 ABP = 10 ** B0
3290 IF (ANS(3).EQ."YES") GO TO 3820
3300 PRINT B2
3310 B20 FORMAT(11,75(" ") / 11, "RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE")
3320 GO TO 3860
3330 3820 PRINT B2
3340 B2 FORMAT(11,75(" ") / 11, "RESULTS OF REGRESSION ON PRODUCTION",
3350 " RATE VARIABLE ALONE", / 11, 75(" ") / 11, "CASE", 31, "OBSERVED", 51,
3360 "PREDICTED", 51, "RESIDUAL", 51, "% DEVIATION")
3370 3860 DO 111 I=1, NCASES
3380 THATL = B0 + B2 * X2(I)
3390 RESIDL = Y(I) - THATL
3400 SSEL2 = SSEL2 + RESIDL ** 2
3410 SSTOL2 = SSTOL2 + (Y(I) - YBAR) ** 2
3420 THAT = 10 ** THATL
3430 RESID(I) = HRS(I) - THAT
3440 PERCENT = (RESID(I) / HRS(I)) * 100
3450 SSEZ = SSEZ + RESID(I) ** 2
3460 SSTOZ = SSTOZ + (HRS(I) - HRSBAR) ** 2
3470 WRITE("REDHOURS", 20) THAT, RESID(I)
3480 IF (ANS(3).EQ."NO") GO TO 111
3490 PRINT B0, I, HRS(I), THAT, RESID(I), PERCENT
3500 111 CONTINUE
3505 CLOSE(FILE="REDHOURS")
3510 CALL SYSTEM('/SORT## REDHOURS; REDCURVE12R01-1,-2', 43340)
3520 DO 3314 I=1, NCASES
3530 READ('REDCURVE', *) THAT, RESID(I)
3531 SUMRESID = SUMRESID + RESID(I) ** 2
3540 IF (I.GT.1)
3550 RESIDIF = RESID(I) - RESID(I-1)
3560 RESIDIF2 = RESIDIF ** 2
3570 RESIDSUM = RESIDSUM + RESIDIF2
3590 ENDF
3600 3314 CONTINUE

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3610 DXSTAT=RESIDSUM/SUMRESID
3620 SUMRESID=RESIDSUM#
3630C:.....
3640C  CALCULATE AND PRINT STATISTICS FOR THE REDUCED HRS VS RATE MODEL
3650C:.....
3660 3310 TMSQL=(SSTOL2-SSEL2)
3670  TMSQL = SSEL2 / NDFD
3680  SEE  = SQRT(TMSQL)
3690  VARB4 = SEE / (1 / NCASES + X2BAR ** 2 / (SS12 - (SUM12 ** 2 / NCASES)))
3700  SEB4  = SQRT (VARB4)
3710  SEB2  = SEE / (SQRT (SS12 - (SUM12 ** 2 / NCASES)))
3720  RSOL2  = (SSTOL2 - SSEL2) / SSTOL2
3730  RSQA2  = (SSTO2 - SSE2) / SSTO2
3740  FRATIO = TMSQL / TMSQL
3750  PRINT 83,B4,SEB4,B2,SEB2,RSOL2,SEE,TMSQL,TMSQL,FRATIO,NDFD,RSQA2,DXSTAT
3760 83 FORMAT(1X75(" ")/1X"THE EQUATION FOR THIS MODEL IS: "
3770  "  THAT = B4 + X2 ** B2"/1X
3780  "LK LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B4) + B2 * LOG(X2)",
3790  /1X,"WHERE: LOG(B4) ="F8.5,4X,"STD ERROR ="F8.5,4X,"B4 ="F11.5,
3800  /1X,"B2 ="F8.5,4X,"STD ERROR ="F8.5,
3810  /1X,"SUMMARY STATISTICS:"/1X,
3820  "R SQUARED LOG  ="F7.5,16X,"STD ERROR EST ="F11.4,1X,
3830  "MSE",1X,"="F9.5,8X,"MSR",1X,"="F9.5,1X,
3840  "F RATIO",9X,"="F9.4,8X,"D. F. (N/D)  = 1/",13,1X,
3850  "R SQUARED ACTUAL="F7.5,1X"DURBIN-WATSON STATISTIC="F9.6/1X75(" ")
3860C:.....
3870C  CALCULATE AND PRINT THE REGRESSION RESULTS FOR THE FULL MODEL
3880C:.....
3890  DENOM = ((SSX1-X1BAR*SUM11)*(SSX2-X2BAR*SUM12) - (SUM112-X1BAR*SUM12)*X2)
3900  B1 = ((SSX2-X2BAR*SUM12)*(SUM112-X1BAR*SUM12) - (SUM112-X1BAR*SUM12)*X2) / DENOM
3910  B2 = ((SSX1-X1BAR*SUM11)*(SUM112-X1BAR*SUM12) - (SUM112-X1BAR*SUM12)*X2) / DENOM
3920  B2 = ((SSX1-X1BAR*SUM11)*(SUM112-X1BAR*SUM12) - (SUM112-X1BAR*SUM12)*X2) / DENOM
3930  B2 = ((SSX1-X1BAR*SUM11)*(SUM112-X1BAR*SUM12) - (SUM112-X1BAR*SUM12)*X2) / DENOM
3940  B4 = TBAR-B1*X1BAR-B2*X2BAR
3950  AB4 = 10.**80
3960 IF(ANS13).EQ."YES")GO TO 4320
3970 PRINT 840
3980 840 FORMAT(1X75(" ")/1X,"RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL")
3990 GO TO 4360
4000 4320 PRINT 84
4010  84 FORMAT(1X,75(" ")/1X,"RESULTS OF COMBINED CUMULATIVE PRODUCTION",
4020  " AND PRODUCTION RATE MODEL"/1X,75(" ")/1X,"CASE",3X,"OBSERVED",5X,
4030  "PREDICTED",5X,"RESIDUAL",5X,"% DEVIATION")
4040 4360 DO 112 1=1,NCASES
4050  THATL = B4 + B1 * X1(I) + B2 * X2(I)
4060  RESIDL = T(I) - THATL
4070  SSEL  = SSEL + RESIDL ** 2
4080  SSTOL = SSTOL + (T(I) - TBAR) ** 2
4090  THAT  = 10 ** THATL
4100  RESID(I) = HRS(I) - THAT
4110  PERCENT = (RESID(I) / HRS(I)) * 100
4120  SSE  = SSE + RESID(I) ** 2

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413#      SSTO = SSTO + (HRS(1) - HRSBAR) ** 2
414# WRITE('FULLMODEL',26)THAT,RESID(1)
415# IF(ANS(3).EQ.'NO')GO TO 112
416#      PRINT 6F,1,HRS(1),THAT,RESID(1),PERCENT
417# 112 CONTINUE
4175 CLOSE(FILE='FULLMODEL')
418# CALL SYSTEM('/SORT** FULLMODEL:FULCURVE;2R6;-1,-2',4389#)
419# DO 3664 I=1,NCASES
420# READ('FULCURVE',*)THAT,RESID(1)
421# SUMRESID=SUMRESID+RESID(1)**2
421# IF(1.GT.1)
422# RESIDIF=RESID(1)-RESID(I-1)
423# RESIDIF2=RESIDIF**2
424# RESIDSUM=RESIDSUM+RESIDIF2
426# ENDIF
427# 3664 CONTINUE
428# DNSTAT=RESIDSUM/SUMRESID
429# SUMRESID=RESIDSUM-#
43#8C      CALCULATE AND PRINT STATISTICS FOR THE FULL MODEL
431#C:.....
432#C:.....
433# 389# NDFD=NCASES-3
434#      THSEL = (SSTOL - SSEL) / 2
435#      THSEL = SSEL / NDFD
436#      SEE = SORT(THSEL)
437#      ZVAL = NCASES*(SSX1 + SSX2 - SMX1X2 ** 2) - SUM11*(SUM11 + SSX2 -
438# SMX1X2 + SUM12) + SUM12*(SUM11 + SMX1X2 - SS11 + SUM12)
439#      AVAL = (SSX1 + SSX2 - SMX1X2 ** 2) / ZVAL
440#      VARBB = THSEL + AVAL
441#      SEBB = SORT (VARBB)
442#      SEB1 = SORT((THSEL + (SSX2 - X2BAR + SUM12)) / DENOM)
443#      SEB2 = SORT((THSEL + (SSX1 - X1BAR + SUM11)) / DENOM)
444#      RSQL = (SSTOL - SSEL) / SSTOL
445#      RSOA = (SSTO - SSE) / SSTO
446#      FRATIO= THSEL / THSEL
447#      FB1 = (RSQL - RSQL2) / ((1 - RSQL) / (NCASES - 3))
448#      FB2 = (RSQL - RSQL1) / ((1 - RSQL) / (NCASES - 3))
449#      PRINT 85,86,SEBB,ACB,B1,SEB1,FB1,82,SEB2,FB2,RSQL,SEE,THSEL,THSEL,FRATIO,NDFD,RSOA,DNSTAT
450# 85 FORMAT(11,75(' '),/,1X,"THE EQUATION FOR THIS MODEL IS: ",
451# " THAT = B0 + X1 ** B1 + X2 **B2",/,1X,
452# "IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)",
453# /,1X,"WHERE: LOG(B0) =",F8.5,4X,"STD ERROR =",F8.5,4X,"B0 =",F11.5,
454# /,13X,"B1 =",F8.5,4X,"STD ERROR =",F8.5,4X,"F0 =",F16.4,/,
455# 13X,"B2 =",F8.5,4X,"STD ERROR =",F8.5,4X,"F0 =",F16.4,/,1X,
456# "SUMMARY STATISTICS:",/,1X,"R SQUARED LOC =",F7.5,10X,
457# "STD ERROR EST =",F11.4,/,1X,"MSE",13X,"=",F9.5,8X,"MSR",11X,"=",F9.5,/,1X,
458# "F RATIO",9X,"=",F9.4,8X,"D. F. (N/D) = 2/",13,/,1X,
459# "R SQUARED ACTUAL="F7.5/1X"DURBIN-WATSON STATISTIC="F9.6/115(' ')
46#8C:.....
461#C
462#C      PART III - PREDICTIVE ABILITY TEST OPTION
463#C
464#C:.....

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4658 IF (ANS(3).EQ."NO") GO TO 116
4660 IF (ANS(3).EQ."NO") PRINT 4173
4661 ITRUNC=NCASES-ITRUNC+1
4672 ITGEUF=NCASES-ITGEUF+1
4680 DO 113 I=ITGEUF,ITRUNC
4690 ITEST = NCASES + 1 - I
4700 4173 FORMAT(//)
4710 IF (ANS(3).EQ."NO") GO TO 4980
4720 PRINT 86,ITEST,HRS(ITEST)
4730 86 FORMAT(1X,116("I"),/,1X,"I",3X,"SHORTRANGE PREDICTIVE ABILITY ",
4740 "COMPARISON",3X,"I",/,1X,"I",16X,
4750 "THE DATA PRESENTED BELOW IS FOR CASE #",I3," WHICH HAS AN OBSERVED",
4760 " VALUE OF:",F9.2,16X,"I",/,
4770 1X,116("I"),/,1X,"I",3X,"I",3X,"I",9X,"REDUCED (LEARNING CURVE) ",
4780 "MODEL",6X,"I",3X,"FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) ",
4790 "MODEL",2X,"I",/,1X,"I",," CASES ",I98("I"),/,1X,"I",," USED ",
4800 "PREDICTION + 1 DEVIATION + EST B0 + EST B1 + ",
4810 "PREDICTION + 1 DEVIATION + EST B0 + EST B1 + EST B2 + ",
4820 /,1X,116("I"))
4830 4980 DO 114 J=1,ITRUNC
4840 ICASES = ITEST - J
4850 SUNT = 0
4860 SUMX1 = 0
4870 SUMX2 = 0
4880 SSX1 = 0
4890 SSX2 = 0
4900 SUMX1Y = 0
4910 SUMX2Y = 0
4920 SX1X2 = 0
4930 DO 115 K=1,ICASES
4940 SUNT = SUNT + T(K)
4950 SUMX1 = SUMX1 + X1(K)
4960 SUMX2 = SUMX2 + X2(K)
4970 SSX1 = SSX1 + X1(K) ** 2
4980 SSX2 = SSX2 + X2(K) ** 2
4990 SUMX1Y = SUMX1Y + X1(K) * T(K)
5000 SUMX2Y = SUMX2Y + X2(K) * T(K)
5010 SX1X2 = SX1X2 + X1(K) * X2(K)
5020 115 CONTINUE
5030 ICOUNTA = ICOUNTA + 1
5040 TBAR = SUNT / ICASES
5050 X1BAR = SUMX1 / ICASES
5060 X2BAR = SUMX2 / ICASES
5070 B1R = (SUMX1Y - ((SUMX1 * SUNT) / ICASES)) / (SSX1 - (SUMX1 ** 2 / ICASES))
5080 B0R = TBAR - B1R * X1BAR
5090 AB0R = 10 ** B0R
5100 TNATR = 10 ** (B0R + B1R * X1(ITEST))
5110 DEVR = HRS(ITEST) - TNATR
5120 ADEVR(ICOUNTA) = ABS(DEVR)
5130 SUMADEVR = SUMADEVR + ADEVR(ICOUNTA)
5140 PDEVR = 100 * DEVR/HRS(ITEST)
5150 APDEVR = ABS(PDEVR)

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5170 IF (APDEVR.CT.12.0) GO TO 201
5170 ICOUNTCR = ICOUNTCR + 1
5180 IF (APDEVR.CT.5.0) GO TO 201
5190 ICOUNTER = ICOUNTER + 1
5200 DENOM = ((SS11-X1EPR+SUM11)+(SS12-X2EPR+SUM12) - (SM112-X1BAR+SUM12))*2
5210 B1F = ((SS12-X2BAR+SUM12)+(SUM111-X1BAR+SUM11) -
5220 (SM112-X1BAR+SUM12)+(SUM121-X2BAR+SUM11))/DENOM
5230 B2F = ((SS11-X1BAR+SUM11)+(SUM121-X2BAR+SUM11) -
5240 (SM112-X1BAR+SUM12)+(SUM111-X1BAR+SUM11))/DENOM
5250 B8F = TBAR - B1F + X1BAR - B2F + X2BAR
5260 AB8F = 10 ** B8F
5270 THATF = 10 ** (B8F + B1F + X1(1TEST) + B2F + X2(1TEST))
5280 DEVF = MRS(1TEST) - THATF
5290 ADEVF(1COUNTA) = ABS(DEVF)
5300 SUMADEVF = SUMADEVF + ADEVF(1COUNTA)
5310 PDEVF = 100 * DEVF/MRS(1TEST)
5320 APDEVF = ABS(PDEVF)
5330 IF (APDEVF.CT.10.0) GO TO 202
5340 ICOUNTCF = ICOUNTCF + 1
5350 IE (APDEVF.CT.5.0) GO TO 202
5360 ICOUNTERF = ICOUNTERF + 1
5370 202 IF (ANS(3).EQ."NO")GO TO 114
5380 PRINT 87, ICASES, THATF, PDEVF, AB8F, B1F, B2F
5390 87 FORMAT(11,"*",2X,13,2X,"*",1X,F9.2,2X,"*",3X,F6.2,4X,"*",F9.2,1X,
5400 " ",F8.5,1X,"*",1X,F9.2,2X,"*",3X,F6.2,4X,"*",F9.2,1X,"*",F8.5,1X,
5410 " ",F8.5,1X,"*")
5420 114 CONTINUE
5430 IF (ANS(3).EQ."NO")GO TO 5590
5440 PRINT 88
5450 88 FORMAT(1X,116(" "),//////)
5460 5590 COUNT=COUNT+1.
5470 FLAG1 = COUNT / 2.0
5480 FLAG2 = FLAG1 - INT(FLAG1)
5490 IF (FLAG2.NE.0.0) GO TO 113
5500 113 CONTINUE
5510 AVCADEVR = SUMADEVR / 1COUNTA
5520 AVCADEVF = SUMADEVF / 1COUNTA
5530 DO 119 I = 1, 1COUNTA
5540 SSDEVR = SSDEVR + (ADEVR(I) - AVCADEVR)**2
5550 SSDEVF = SSDEVF + (ADEVF(I) - AVCADEVF)**2
5560 119 CONTINUE
5570C.....
5580C CALCULATE AND PRINT RESULTS SUMMARY FOR PREDICTIVE ABILITY TESTS
5590C.....
5600 VARADEVR = SSDEVR / (1COUNTA - 1)
5610 VARADEVF = SSDEVF / (1COUNTA - 1)
5620 TESTSTAT = (AVCADEVR-AVCADEVF)/SQRT((VARADEVR/1COUNTA)+(VARADEVF/1COUNTA))
5630 PCENTER = 100 * ICOUNTER / 1COUNTA
5640 PCENTCR = 100 * ICOUNTCR / 1COUNTA
5650 PCENTERF = 100 * ICOUNTERF / 1COUNTA
5660 PCENTCF = 100 * ICOUNTCF / 1COUNTA
5670 PRINT 95, AVCADEVR, AVCADEVF, VARADEVR, VARADEVF, TESTSTAT, 1COUNTA,

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56994 ICOUNTA,ICOUNTER,ICOUNTERF,PCENTER,PCENTERF,ICOUNTA,ICOUNTERF,PCENTER,
56996 PCENTERF
5779 95 FORMAT(11,67(" "),//11,"",18X,"SUMMARY OF PREDICTIVE ABILITY TESTS",
5780 " RESULTS",121,"",//11,67(" "),//11,"",91,"ITEMS OF INTEREST",81,
5781 " REDUCED MODEL * FULL MODEL ",//11,67(" "),//11," AVERAGE ",
5782 "ABSOLUTE DEVIATION",71,"",31,F9.2,31,"",21,F9.2,31,"",//11,
5783 " VARIANCE OF ABSOLUTE DEVIATIONS",21,"",11,F11.2,31,"",F11.2,31,
5784 " ",//11," TEST STATISTIC (SEE NOTE)",81,"",61,"---",61,"",21,
5785 F9.2,31,"",//11," TOTAL NUMBER OF TEST SITUATIONS ",61,13,61,"",
5786 51,13,61,"",//11," NUMBER OF PREDICTIONS WITHIN 5% ",61,13,61,
5787 " ",51,13,61,"",//11," PERCENT OF PREDICTIONS WITHIN 5% ",61,F4.8,
5788 51,"",51,F4.8,51,"",//11," NUMBER OF PREDICTIONS WITHIN 10% ",
5789 61,13,61,"",51,13,61,"",//11," PERCENT OF PREDICTIONS WITHIN 10%",
5790 61,F4.8,51,"",51,F4.8,51,"",//11,67(" "),//11,"NOTE: IN TESTING FOR ",
5791 "STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION",//11,
5792 "IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 40; OTHERWISE ",
5793 "USE STANDARD",//11,"NORMAL DISTRIBUTION. IN EITHER CASE THIS IS ",
5794 "A ONE TAILED TEST. IF",//11,"THE TEST STATISTIC IS GREATER THAN ",
5795 "THE CRITICAL STATISTIC ONE MAY",//11,"CONCLUDE THAT THE AVERAGE ",
5796 "ABSOLUTE DEVIATION OBTAINED WITH THE FULL",//11,"MODEL IS ",
5797 "SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL.")
5798 PRINT,"FILES LOGFILE,STDLEARN,REDHOURS,AND FULLMODEL WRITTEN."
5799 *****
5810C
5820C PART IV - PROJECTION AND SENSITIVITY MATRIX OPTION
5830C
5840C *****
5950 116 IF (ANSWER(4).EQ."NO") GO TO 125
5960 ADDPLOT = PLOT(NCASES)
5970 DO 117 I=1,100
5980 ADDPLOT = ADDPLOT + .01 * PLOT(NCASES)
5990 NEWPLOT(I) = INT(ADDPLOT)
6000 ADDRATE = .60 * RATE(NCASES)
6010 DO 118 J=1,9
6020 ADDRATE = ADDRATE + .1 * RATE(NCASES)
6030 PRORATE(J) = ADDRATE
6040 FHRS(I,J) = ADD * NEWPLOT(I)*.01 + PRORATE(J)*.02
6050 118 CONTINUE
6060 117 CONTINUE
6070 ISTART = 1
6080 ISTOP = 50
6090 DO 120 K=1,2
6100 PRINT 89,(PRORATE(J),J=1,9)
6110 89 FORMAT(11,113(" "),//11,"",39X,"PROJECTION AND SENSITIVITY MATRIX",
6120 39X,"",//11,113(" "),//11," PROJECTED ",31,"PROJECTED PRODUCTION",
6130 " RATES",36X,"",//11," CUMULATIVE ",99(" "),//11," UNITS ",
6140 9(F8.2,21,"",//11,113(" "))
6150 DO 121 I=ISTART,ISTOP
6160 PRINT 90,NEWPLOT(I),(FHRS(I,J),J=1,9)
6170 90 FORMAT(11,"",31,16,31,"",9(11,F8.1,11," "))
6180 121 CONTINUE
6190 PRINT 91

```

```

6200 9: FORMAT(11,113(" "))
6210 PRINT#2
6220 92 FORMAT(11,"NOTE: 1. PROJECTED VALUES FOR DIRECT LABOR HOURS MAY ",
6230 "BE READ FROM THE ABOVE MATRIX BY MATCHING A GIVEN PRODUCTION",11,
6240 "RATE WITH A GIVEN NUMBER OF CUMULATIVE UNITS AND READING THE ",
6250 "VALUE FOR DIRECT LABOR HOURS FOUND AT THE INTERSECTION",11,
6260 "OF THE CORRESPONDING ROW AND COLUMN. FORECASTING MODEL IS THE ",
6270 "CUMULATIVE PRODUCTION & PRODUCTION RATE MODEL.",11,"2. PROJECT",
6280 "ION INTERVAL FOR CUMULATIVE UNITS IS 12 OF THE LAST OBSERVED VALUE",
6290 " OF CUMULATIVE UNITS.",11,"3. PROJECTION VALUES FOR PRODUCTION ",
6300 "RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF ",
6310 "THE",11,"LAST OBSERVED VALUE OF PRODUCTION RATE.")
6320 ISTART = 51
6330 ISTOP = 100
6340 120 CONTINUE
6350 125 STOP
6360 END

```

### Sample PRODRATE Output

This next section provides a sample output of the abbreviated and full format options using simulated data. The data base was developed by Stevens and Thomerson (15:127) to demonstrate how the PRODRATE program works. It should be noted the data were developed to demonstrate superior results for the full model. The program instructions are presented first, then the abbreviated format followed by the full format. This comparison of the optional formats will, hopefully, demonstrate the value of the abbreviated option.

# PRODRATE INSTRUCTIONS

THIS PROGRAM IS DESIGNED TO EVALUATE THE VARIATION IN DIRECT LABOR REQUIREMENTS AS A FUNCTION OF CUMULATIVE PRODUCTION AND PRODUCTION RATE. IN ADDITION, THE ANALYST MAY COMPARE THE RESULTS OBTAINED FROM THE STANDARD LEARNING CURVE WITH THE RESULTS OBTAINED FROM THE CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL. THE COST MODELS USED IN THIS PROGRAM ARE:

## 1. REDUCED MODEL (STANDARD LEARNING CURVE MODEL)

$$Y = B0 + (X1 * B1) + (10 * E)$$

## 2. FULL MODEL (CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL)

$$Y = B0 + (X1 * B1) + (X2 * B2) + (10 * E)$$

WHERE: Y IS THE DIRECT LABOR REQUIREMENTS  
 X1 IS THE CUMULATIVE PRODUCTION PLOT POINT  
 X2 IS THE PRODUCTION RATE PROXY (E.C. EQUIVALENT UNITS PER MONTH)  
 E REPRESENTS THE ERROR TERM  
 B0, B1, AND B2 ARE PARAMETERS DETERMINED BY REGRESSION

DATA ARE INPUT BY READING FROM ANY PROPERLY FORMATTED DATA FILE. YOUR DATA FILE SHOULD BE SAVED TO ANY PERMANENT FILENAME. YOU WILL BE ASK TO INPUT THE NAME OF YOUR DATA FILE AT THE APPROPRIATE STEP IN THE PROGRAM. THE NAME OF YOUR DATA FILE CAN NOT EXCEED 8 CHARACTERS. THE FIRST LINE OF THE DATA FILE MUST CONTAIN A LINE NUMBER AND THE NUMBER OF CASES TO BE READ. THE DATA IS THEN ENTERED ONE CASE PER LINE IN THE FOLLOWING ORDER: LINE NUMBER, OBSERVED DIRECT LABOR REQUIREMENT (Y), CUMULATIVE PRODUCTION PLOT POINT (X1), AND PRODUCTION RATE PROXY (X2). THE PROGRAM USES A FREE FIELD READ FORMAT; THEREFORE, EACH VARIABLE MUST BE SEPARATED BY AT LEAST ONE SPACE (OR OTHER DELIMITER) BUT NO OTHER SPECIAL FORMAT IS REQUIRED. AN EXAMPLE OF A DATA FILE WITH 5 CASES IS PRESENTED BELOW:

100	5		
101	100	9.5	9.5
102	90	30	20.5
103	80	55	25
104	75	62	27
105	71	113	31

ONE ADVANTAGE OF THIS PROGRAM IS THAT THE RESULTS OBTAINED WILL BE IN THE SAME UNITS AND FORM AS THE INPUT DATA. FOR EXAMPLE, IF YOU ARE WORKING IN DIRECT LABOR HOURS PER MONTH AND EQUIVALENT UNITS, THE RESULTS WILL BE IN TERMS OF THESE UNITS. ALSO, IF YOU WISH TO USE A CUMULATIVE AVERAGE APPROACH, ALL YOU NEED DO IS AGGREGATE THE DATA BASE IN THAT MANNER.

THE PROGRAM BEGINS BY TRANSFORMING THE INPUT DATA TO COMMON LOGARITHMS. LOG LINEAR REGRESSION IS THEN PERFORMED AS FOLLOWS: Y REGRESSED ON X1, Y REGRESSED ON X2, AND FINALLY Y REGRESSED ON BOTH X1 AND X2. OBSERVED DIRECT LABOR REQUIREMENTS, PREDICTED DIRECT LABOR REQUIREMENTS, AND RESIDUALS ARE PRINTED IN ORIGINAL (UNTRANSFORMED) FORM FOR EACH REGRESSION SITUATION. IN ADDITION, SUMMARY STATISTICS ARE PRINTED FOR EACH MODEL. THE SUMMARY STATISTICS INCLUDE TWO COEFFICIENTS OF DETERMINATION R SQUARED LOG AND R SQUARED ACTUAL. THE R SQUARED LOG REPRESENTS THE GOODNESS OF FIT OF THE MODEL TO THE TRANSFORMED DATA (LOG FORM). THE R SQUARED ACTUAL, ON THE OTHER HAND, IS COMPUTED USING THE UNTRANSFORMED RESIDUALS, AND IS REPRESENTATIVE OF HOW WELL THE MODEL FITS THE UNTRANSFORMED DATA. THE BURDIN-WATSON STATISTIC IS CALCULATED FOR ASSESSMENT OF AUTOCORRELATION OF THE RESIDUALS.

SEVERAL OPTIONS ARE AVAILABLE WITHIN THIS PROGRAM AND CAN BE SELECTED BY APPROPRIATE ANSWERS TO THE FOLLOWING QUESTIONS:

1. DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE ..... AND CONVERTED TO LOGARITHMS?

YES - WILL CAUSE THE PRINTING OF A LISTING OF THE RATIONAL INPUT DATA AND THE ASSOCIATED LOGARITHMIC VALUES.

NO - SUPPRESSES THIS OPTION.

2. COMPLETE PRINTOUT?

YES - WILL CAUSE OUTPUT TO BE PRINTED IN FULL FORMAT AS DESCRIBED ABOVE.

NO - WILL DELETE THE LISTING OF OBSERVED, PREDICTED, AND RESIDUAL VALUES BETWEEN TABLES OF SUMMARY STATISTICS. IT WILL ALSO DELETE LISTING OF INDIVIDUAL MATRICES FOR THE SHORTRANGE PREDICTIVE ABILITY OPTION(I.E., ONLY THE SUMMARY TABLE WILL BE LISTED).

3. DO YOU WANT A COMPARISON OF THE SHORTRANGE PREDICTIVE ABILITY OF THE TWO MODELS?

YES - WILL CAUSE THE PREDICTIVE ABILITY TEST OPTION TO BE ACTIVATED AND THE USER WILL BE TOLD: 'ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES).' THE USER SHOULD ENTER THE NUMBER OF THE FIRST CASE TO BE PREDICTED FOLLOWED BY THE LAST CASE TO BE PREDICTED, SEPARATED BY A COMMA. THE CASE NUMBERS MUST BE INTEGER VALUES GREATER THAN OR EQUAL TO 2. THE PREDICTIVE ABILITY TEST SIMULATES FUTURE PREDICTIONS BY PERFORMING A STEPWISE TRUNCATION OF THE HISTORICAL DATA. FOR THIS REASON, AN UPPER LIMITATION ON THE NUMBER OF CASES TRUNCATED WOULD BE:  $((\text{TOTAL NUMBER OF CASES IN DATA FILE}) / 2) - 2$ . FOR EXAMPLE, IF YOUR DATA FILE CONTAINS 50 CASES, YOUR UPPER LIMIT WOULD BE 23 CASES. THIS, OF COURSE, REPRESENTS ONLY THE MAXIMUM NUMBER OF CASES THAT COULD BE TRUNCATED. IN PRACTICE YOU MAY WANT TO TRUNCATE ONLY A SMALL NUMBER OF CASES. THUS, IF YOUR DATA IS COLLECTED IN MONTHLY INTERVALS, YOU CAN LOOK AT THE PREDICTIVE ABILITY OF THE FULL AND REDUCED MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING AN 18 CASE RANGE. IF YOUR DATA IS COLLECTED IN QUARTERS, YOU CAN LOOK AT THE PREDICTIVE ABILITY OF BOTH MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING '6'. AFTER ALL PREDICTIVE ABILITY TEST SITUATIONS ARE PRINTED, THE PROGRAM PRINTS A SUMMARY OF THE TEST RESULTS.

NO - SUPPRESSES THIS OPTION.

4. DO YOU WANT PROJECTION AND SENSITIVITY MATRIX?

YES - WILL CAUSE PRINTING OF PROJECTION AND SENSITIVITY MATRIX. THIS MATRIX PRESENTS PROJECTED DIRECT LABOR REQUIREMENTS FOR SELECTED PAIRS OF CUMULATIVE PRODUCTION PLOT POINTS AND PRODUCTION RATES. THE PROJECTION INTERVAL FOR THE CUMULATIVE PRODUCTION PLOT POINT IS 1% OF THE LAST OBSERVED VALUE. THE PROJECTION VALUES FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF THE LAST OBSERVED VALUE OF PRODUCTION RATE.

NO - SUPPRESSES THIS OPTION.

\*\*\*SPECIAL NOTE\*\*\* THE PREDICTED DIRECT LABOR REQUIREMENTS AND RESIDUALS FOR EACH MODEL ARE STORED IN SEPARATE FILES. THE VALUES FOR THE STANDARD LEARNING CURVE MODEL ARE STORED IN A FILE CALLED 'STDLearn'; THE VALUES FOR THE PRODUCTION RATE VARIABLE ALONE MODEL IN THE FILE 'REDHOURS'; AND THE VALUES FOR THE COMBINED CUM. PRODUCTION AND PRODUCTION RATE MODEL IN THE FILE 'FULLMODEL'. USERS MAY ACCESS THESE FILES FOR RESIDUAL ANALYSIS BY OTHER COPPER IMPACT STATISTICAL PROGRAMS, IF DESIRED.

PEARSON CORRELATION COEFFICIENTS MATRIX

	Y	X1	X2
Y	1.000000	-0.995571	-0.984143
X1	-0.995571	1.000000	0.996468
X2	-0.984143	0.996468	1.000000

RESULTS OF STANDARD LEARNING CURVE MODEL

THE EQUATION FOR THIS MODEL IS:  $YHAT = B0 + X1 * B1$   
 IN LOG FORM THIS MODEL BECOMES:  $LOG(YHAT) = LOG(B0) + B1 * LOG(X1)$   
 WHERE:  $LOG(B0) = 3.49572$   $STD ERROR = 0.13455$   $B0 = 3131.24884$   
 $B1 = -0.28262$   $STD ERROR = 0.00433$

SUMMARY STATISTICS:

R SQUARED LOG	=0.99115	STD ERROR EST	= 0.0164
KSE	= 0.00027	KSR	= 1.14396
F RATIO	=4255.4085	D. F. (N/D)	= 1/ 38
R SQUARED ACTUAL	=0.98881	LEARNING FACTOR	= 82.28945 PERCENT
DURBIN-WATSON STATISTIC	= 0.327753		

RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE

THE EQUATION FOR THIS MODEL IS:  $YHAT = B0 + X2 * B2$   
 IN LOG FORM THIS MODEL BECOMES:  $LOG(YHAT) = LOG(B0) + B2 * LOG(X2)$   
 WHERE:  $LOG(B0) = 3.25379$   $STD ERROR = 0.23957$   $B0 = 1793.86998$   
 $B2 = -0.74392$   $STD ERROR = 0.02175$

SUMMARY STATISTICS:

R SQUARED LOG	=0.94854	STD ERROR EST	= 0.0389
KSE	= 0.00096	KSR	= 1.11708
F RATIO	=1145.7958	D. F. (N/D)	= 1/ 38
R SQUARED ACTUAL	=0.95679		
DURBIN-WATSON STATISTIC	= 0.277285		



```

*****
RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL
*****
THE EQUATION FOR THIS MODEL IS:  THAT = B0 + X1 ** B1 + X2 ** B2
IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)
WHERE: LOG(B0) = 3.75309  STD ERROR = 0.00116  B0 = 5672.64648
      B1 = -0.59957  STD ERROR = 0.00134  F0 = 60532.2109
      B2 = 0.64696  STD ERROR = 0.00356  F0 = 54304.9604
SUMMARY STATISTICS:
R SQUARED LOG = 0.99999  STD ERROR EST = 0.0004
KSE = 0.00000  NSR = 0.57705
F RATIO = 7968.2012  D. F. (N/D) = 2/ 37
R SQUARED ACTUAL = 1.00000
DURBIN-WATSON STATISTIC = 2.380320
*****

```

```

*****
SUMMARY OF PREDICTIVE ABILITY TESTS RESULTS
*****
ITEMS OF INTEREST  * REDUCED MODEL * FULL MODEL *
*****
* AVERAGE ABSOLUTE DEVIATION * 3.84 * 0.16 *
* VARIANCE OF ABSOLUTE DEVIATIONS * 16.60 * 0.01 *
* TEST STATISTIC (SEE NOTE) * --- * 13.50 *
* TOTAL NUMBER OF TEST SITUATIONS * 144 * 144 *
* NUMBER OF PREDICTIONS WITHIN 5% * 130 * 144 *
* PERCENT OF PREDICTIONS WITHIN 5% * 95. * 100. *
* NUMBER OF PREDICTIONS WITHIN 10% * 144 * 144 *
* PERCENT OF PREDICTIONS WITHIN 10% * 100. * 100. *
*****
NOTE: IN TESTING FOR STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION
IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 40; OTHERWISE USE STANDARD
NORMAL DISTRIBUTION. IN EITHER CASE THIS IS A ONE TAILED TEST. IF
THE TEST STATISTIC IS GREATER THAN THE CRITICAL STATISTIC ONE MAY
CONCLUDE THAT THE AVERAGE ABSOLUTE DEVIATION OBTAINED WITH THE FULL
MODEL IS SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL.
FILES LOGFILE,STOLEARN,REDHOURS,AND FULLMODEL WRITTEN.

```

INPUT DATA AS READ FROM FILE TESTDATA AND CONVERTED TO LOGARITHMS

LINE DIRECT LABOR HOURS \* CUR PROD PLOT POINT \* PRODUCTION RATE  
NUMBER RATIONAL LOGARITHM \* RATIONAL LOGARITHM \* RATIONAL LOGARITHM

100	1988.00	3.0366289	58.00	1.4989728	2.27	0.3562259
110	683.00	2.9247155	175.00	2.2438331	3.65	0.5854687
120	641.00	2.6268583	313.00	2.4955443	4.45	0.6483688
130	568.00	2.7481883	454.00	2.6578559	4.94	0.6937269
140	493.00	2.4920469	626.00	2.7965743	5.33	0.7267272
150	482.00	2.6646420	795.00	2.9223671	5.85	0.7671359
160	437.00	2.6404814	1005.00	3.0021661	6.47	0.8189943
170	404.00	2.6063814	1286.00	3.0813473	6.71	0.8267225
180	368.00	2.5658476	1495.00	3.1746412	7.08	0.8458988
190	347.00	2.5463295	1775.00	3.2491983	7.37	0.8674675
200	338.00	2.5185139	2092.00	3.3285617	7.79	0.8915375
210	328.00	2.5351503	2421.00	3.3839748	8.33	0.9266454
220	317.00	2.5818593	2769.00	3.4423229	9.09	0.9585639
230	313.00	2.4955443	3176.00	3.5018685	9.86	0.9938769
240	309.00	2.4899585	3557.00	3.5518839	10.51	1.0214827
250	304.00	2.4828736	3976.00	3.5994464	11.17	1.0488532
260	298.00	2.4742163	4452.00	3.6488552	11.88	1.0718829
270	296.00	2.4625988	4964.00	3.6958318	12.37	1.0923697
280	284.00	2.4533183	5458.00	3.7378535	12.87	1.1095785
290	278.00	2.4440448	5959.00	3.7751734	13.38	1.1264561
300	270.00	2.4313638	6461.00	3.8182997	13.65	1.1351327
310	263.00	2.4199557	6972.00	3.8433574	13.98	1.1455872
320	256.00	2.4382488	7491.00	3.8745398	14.23	1.1532849
330	250.00	2.3979408	8088.00	3.9074114	14.65	1.1658376
340	245.00	2.3891661	8458.00	3.9378161	14.98	1.1755118
350	239.00	2.3783979	9248.00	3.9668478	15.29	1.1844875
360	235.00	2.3718679	9848.00	3.9933488	15.65	1.1945143
370	232.00	2.3654888	10458.00	4.0191163	16.04	1.2052844
380	228.00	2.3579348	11031.00	4.0426149	16.35	1.2135178
390	224.00	2.3502488	11626.00	4.0654383	16.66	1.2216758
400	221.00	2.3443923	12227.00	4.0873199	16.97	1.2296818
410	218.00	2.3384565	12838.00	4.1084974	17.27	1.2372922
420	216.00	2.3344537	13349.00	4.1254487	17.56	1.2445245
430	214.00	2.3304438	13849.00	4.1414184	17.81	1.2506639
440	211.00	2.3242624	14337.00	4.1564583	18.01	1.2553137
450	209.00	2.3281463	14866.00	4.1721941	18.22	1.2605484
460	206.00	2.3128672	15454.00	4.1898439	18.41	1.2653538
470	203.00	2.3074968	16048.00	4.2054289	18.58	1.2698457
480	200.00	2.3018388	16654.00	4.2215166	18.78	1.2736956
490	198.00	2.2966452	17172.00	4.2348288	18.94	1.2773888

PEARSON CORRELATION COEFFICIENTS MATRIX

	1	2	3
1	1.0000000	-0.9955718	-0.9841432
2	-0.9955718	1.0000000	0.9964648
3	-0.9841432	0.9964648	1.0000000

```

.....
RESULTS OF THE STANDARD LEARNING CURVE MODEL
.....
CASE  OBSERVED    PREDICTED    RESIDUAL    1 DEVIATION
1      1808.00      1836.45      51.55       4.74
2      893.00      727.41      75.59       9.41
3      641.00      617.19      23.81       3.71
4      560.00      555.61      4.39       0.78
5      493.00      587.39     -14.39      -2.92
6      462.00      474.25     -12.25      -2.65
7      437.00      443.85      -6.85      -1.57
8      404.00      421.56     -17.56      -4.35
9      368.00      396.72     -28.72      -7.81
10     347.00      377.93     -30.93     -8.91
11     338.00      368.78     -30.78     -9.33
12     328.00      346.19     -26.19     -8.19
13     317.00      333.38     -16.38     -5.14
14     313.00      328.63     -15.63     -4.44
15     309.00      318.52     -9.52      -6.49
16     304.00      309.98      3.98       1.82
17     298.00      291.44      6.56       2.28
18     298.00      282.61      7.39       2.55
19     284.00      275.13      8.87       3.12
20     278.00      268.39      9.61       3.46
21     278.00      262.32      7.68       2.84
22     263.00      256.74      6.26       2.38
23     256.00      251.58      4.42       1.73
24     250.00      246.26      3.74       1.56
25     245.00      241.56      3.44       1.48
26     239.00      237.84      1.16       0.82
27     235.00      232.86      2.14       0.91
28     232.00      228.99      3.01       1.38
29     228.00      225.52      2.48       1.89
30     224.00      222.19      1.81       0.81
31     221.00      219.85      1.15       0.88
32     218.00      216.85      1.15       0.89
33     216.00      213.68      2.32       1.07
34     214.00      211.47      2.53       1.18
35     211.00      209.41      1.59       0.75
36     209.00      207.28      1.72       0.82
37     206.00      205.82      0.18       0.48
38     203.00      202.85      0.15       0.80
39     202.00      200.73      -0.73      -0.37
40     195.00      199.80     -1.80      -0.51
.....
THE EQUATION FOR THIS MODEL IS:  THAT = B0 + I1 ** B1
IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(I1)
WHERE: LOG(B0) = 3.49572  STD ERROR = 0.13455  B0 = 3131.24884
      B1 = -0.28262  STD ERROR = 0.08432
SUMMARY STATISTICS:
R SQUARED LOG = 0.99115  STD ERROR EST = 0.0164
RSE = 0.02927  MSR = 1.14398
F RATIO = 4255.4885  D. F. (N/D) = 1/ 30
R SQUARED ACTUAL = 0.98861  LEARNING FACTOR = 82.28945 PERCENT
DURBIN-WATSON STATISTIC = 0.327753
.....

```

RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE

CASE	OBSERVED	PREDICTED	RESIDUAL	Z DEVIATION
1	1868.88	974.84	113.16	18.48
2	823.88	458.84	144.96	18.85
3	641.88	598.83	58.17	7.83
4	568.88	546.85	13.03	2.38
5	493.88	516.61	-23.61	-4.79
6	462.88	482.84	-20.84	-4.36
7	437.88	447.24	-16.24	-2.34
8	404.88	435.28	-31.28	-7.74
9	368.88	421.88	-53.88	-14.62
10	347.88	405.94	-58.94	-16.99
11	338.88	389.54	-59.54	-18.84
12	328.88	378.68	-58.68	-15.81
13	317.88	347.29	-38.29	-9.56
14	313.88	326.98	-13.98	-4.14
15	309.88	311.74	-2.74	-0.89
16	304.88	297.93	6.87	2.88
17	298.88	286.82	11.98	4.82
18	298.88	276.15	13.85	4.77
19	284.88	268.13	15.87	5.59
20	278.88	268.49	17.51	6.38
21	278.88	256.65	13.25	4.95
22	263.88	252.13	16.87	4.13
23	256.88	248.82	7.18	2.88
24	258.88	243.58	6.58	2.48
25	245.88	239.58	5.58	2.25
26	239.88	235.87	3.13	1.31
27	235.88	231.63	3.17	1.35
28	232.88	227.62	4.38	1.69
29	228.88	224.48	3.68	1.58
30	224.88	221.29	2.71	1.21
31	221.88	218.27	2.73	1.23
32	218.88	215.45	2.55	1.17
33	216.88	212.79	3.21	1.48
34	214.88	218.57	3.43	1.68
35	211.88	208.83	2.17	1.03
36	209.88	207.83	1.97	0.94
37	206.88	205.44	8.54	0.27
38	203.88	204.84	-1.84	-0.51
39	200.88	202.42	-2.42	-1.21
40	198.88	201.15	-3.15	-1.59

THE EQUATION FOR THIS MODEL IS:  $\hat{Y} = B_0 + B_1 X + B_2 X^2$   
 IN LOG FORM THIS MODEL BECOMES:  $\text{LOG}(\hat{Y}) = \text{LOG}(B_0) + B_1 X + \text{LOG}(X^2)$   
 WHERE:  $\text{LOG}(B_0) = 3.25379$  STD ERROR = 0.23957  $B_1 = 1793.84996$   
 $B_2 = -0.74392$  STD ERROR = 0.82175

SUMMARY STATISTICS:  
 R SQUARED LOC = 0.96854 STD ERROR EST = 0.0389  
 MSE = 0.00096 MSR = 1.11788  
 F-RATIO = 1169.7958 D. F. (N/D) = 1/ 38  
 R SQUARED ACTUAL = 0.95479  
 DURBIN-WATSON STATISTIC = 0.277265

\*\*\*\*\*  
 RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL  
 \*\*\*\*\*

CASE	OBSERVED	PREDICTED	RESIDUAL	Z DEVIATION
1	1088.00	1088.13	-0.13	-0.01
2	833.00	833.15	-0.15	-0.02
3	641.00	640.73	0.27	0.04
4	568.00	568.09	-0.09	-0.02
5	493.00	492.67	0.33	0.07
6	462.00	461.92	0.08	0.02
7	437.00	437.10	-0.10	-0.02
8	404.00	404.12	-0.12	-0.03
9	368.00	368.24	-0.24	-0.07
10	347.00	347.04	-0.04	-0.01
11	330.00	329.59	0.41	0.12
12	320.00	319.59	0.41	0.13
13	317.00	317.50	-0.50	-0.16
14	313.00	313.28	-0.28	-0.09
15	309.00	308.97	0.03	0.01
16	304.00	304.32	-0.32	-0.10
17	298.00	297.89	0.11	0.04
18	298.00	298.45	-0.45	-0.15
19	284.00	283.75	0.25	0.09
20	278.00	278.21	-0.21	-0.07
21	270.00	269.56	0.44	0.16
22	263.00	262.88	0.12	0.06
23	256.00	255.53	0.47	0.18
24	250.00	250.29	-0.29	-0.11
25	245.00	244.84	0.16	0.07
26	239.00	239.34	-0.34	-0.14
27	235.00	235.07	-0.07	-0.03
28	232.00	231.63	0.37	0.16
29	228.00	227.91	0.09	0.04
30	224.00	224.38	-0.38	-0.17
31	221.00	221.13	-0.13	-0.06
32	218.00	217.97	0.03	0.02
33	216.00	215.95	0.05	0.02
34	214.00	213.78	0.22	0.10
35	211.00	211.38	-0.38	-0.18
36	209.00	208.88	0.12	0.06
37	206.00	205.88	0.12	0.06
38	203.00	202.85	0.15	0.07
39	200.00	200.28	-0.28	-0.10
40	198.00	197.97	0.03	0.01

\*\*\*\*\*  
 THE EQUATION FOR THIS MODEL IS:  $THAT = B0 + X1 * B1 + X2 * B2$   
 IN LOG FORM THIS MODEL BECOMES:  $LOG(THAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)$   
 WHERE:  $LOG(B0) = 3.75300$   $STD ERROR = 0.00116$   $B0 = 5672.84668$   
 $B1 = -0.59957$   $STD ERROR = 0.00134$   $F = 00532.2109$   
 $B2 = 0.04696$   $STD ERROR = 0.00356$   $F = 54304.9604$

SUMMARY STATISTICS:  
 R SQUARED LOC = 0.99999  $STD ERROR EST = 0.0004$   
 MSE = 0.00000  $MSR = 0.57705$   
 F RATIO = 7900.2012  $D. F. (N/D) = 2 / 37$   
 R SQUARED ACTUAL = 1.00000  
 DURBIN-WATSON STATISTIC = 2.300320  
 \*\*\*\*\*

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 42 WHICH HAS AN OBSERVED VALUE OF: 198.89
*****
# # REDUCED (LEARNING CURVE) MODEL ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL
CASES *****
USED * PREDICTION * Z DEVIATION * EST D0 * EST B1 ** PREDICTION * Z DEVIATION * EST D0 * EST B1 * EST B2 *
*****
# 39 * 199.86 * -0.53 * 3129.81 +-0.28252 ** 197.97 * 0.02 * 5673.27 +-0.59961 * 0.84784 *
# 38 * 199.18 * -0.56 * 3127.28 +-0.28244 ** 197.98 * 0.01 * 5671.21 +-0.59947 * 0.84673 *
# 37 * 199.18 * -0.56 * 3127.32 +-0.28244 ** 197.97 * 0.01 * 5671.58 +-0.59947 * 0.84669 *
# 36 * 199.05 * -0.53 * 3129.39 +-0.28254 ** 197.97 * 0.02 * 5671.34 +-0.59941 * 0.84649 *
# 35 * 198.94 * -0.47 * 3133.42 +-0.28273 ** 197.96 * 0.02 * 5671.37 +-0.59938 * 0.84637 *
# 34 * 198.83 * -0.42 * 3137.51 +-0.28292 ** 197.98 * 0.01 * 5671.01 +-0.59945 * 0.84669 *
# 33 * 198.64 * -0.32 * 3144.39 +-0.28324 ** 197.97 * 0.02 * 5671.22 +-0.59941 * 0.84656 *
# 32 * 198.45 * -0.22 * 3151.43 +-0.28357 ** 197.96 * 0.02 * 5671.63 +-0.59937 * 0.84639 *
# 31 * 198.25 * -0.13 * 3158.24 +-0.28389 ** 197.96 * 0.02 * 5671.17 +-0.59937 * 0.84637 *
# 30 * 198.04 * -0.02 * 3165.76 +-0.28424 ** 197.97 * 0.02 * 5670.86 +-0.59938 * 0.84643 *
# 29 * 197.81 * 0.09 * 3173.66 +-0.28462 ** 198.08 * -0.08 * 5669.98 +-0.59943 * 0.84671 *
# 28 * 197.58 * 0.25 * 3184.44 +-0.28513 ** 198.08 * 0.00 * 5670.65 +-0.59941 * 0.84664 *
*****

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 39 WHICH HAS AN OBSERVED VALUE OF: 208.00
*****
# # REDUCED (LEARNING CURVE) MODEL ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL
CASES *****
USED * PREDICTION * Z DEVIATION * EST D0 * EST B1 ** PREDICTION * Z DEVIATION * EST D0 * EST B1 * EST B2 *
*****
# 38 * 208.83 * -0.42 * 3127.28 +-0.28244 ** 208.21 * -0.10 * 5671.21 +-0.59947 * 0.84673 *
# 37 * 208.83 * -0.42 * 3127.32 +-0.28244 ** 208.20 * -0.10 * 5671.58 +-0.59947 * 0.84669 *
# 36 * 208.78 * -0.39 * 3129.39 +-0.28254 ** 208.19 * -0.10 * 5671.34 +-0.59941 * 0.84649 *
# 35 * 208.67 * -0.33 * 3133.42 +-0.28273 ** 208.18 * -0.09 * 5671.37 +-0.59938 * 0.84637 *
# 34 * 208.56 * -0.28 * 3137.51 +-0.28292 ** 208.21 * -0.10 * 5671.01 +-0.59945 * 0.84669 *
# 33 * 208.37 * -0.19 * 3144.39 +-0.28324 ** 208.19 * -0.10 * 5671.22 +-0.59941 * 0.84656 *
# 32 * 208.18 * -0.09 * 3151.43 +-0.28357 ** 208.19 * -0.09 * 5671.63 +-0.59937 * 0.84639 *
# 31 * 199.99 * 0.01 * 3158.24 +-0.28389 ** 208.19 * -0.09 * 5671.17 +-0.59937 * 0.84637 *
# 30 * 199.77 * 0.11 * 3165.76 +-0.28424 ** 208.20 * -0.10 * 5670.86 +-0.59938 * 0.84643 *
# 29 * 199.55 * 0.23 * 3173.66 +-0.28462 ** 208.23 * -0.11 * 5669.98 +-0.59943 * 0.84671 *
# 28 * 199.23 * 0.39 * 3184.44 +-0.28513 ** 208.22 * -0.11 * 5670.65 +-0.59941 * 0.84664 *
# 27 * 198.83 * 0.59 * 3198.18 +-0.28578 ** 208.19 * -0.09 * 5670.15 +-0.59939 * 0.84619 *
*****

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 36 WHICH HAS AN OBSERVED VALUE OF: 283.88
*****
# # REDUCED (LEARNING CURVE) MODEL # # FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL #
CASES *****
USED * PREDICTION * % DEVIATION * EST D0 * EST D1 * PREDICTION * % DEVIATION * EST D0 * EST D1 * EST D2 *
*****
# 37 # 282.94 # 0.03 # 3127.32 +-0.28244 # 282.05 # 0.07 # 5671.58 +-0.59947 # 0.84669 #
# 36 # 282.89 # 0.05 # 3129.39 +-0.28254 # 282.84 # 0.08 # 5671.34 +-0.59941 # 0.84649 #
# 35 # 282.78 # 0.11 # 3133.42 +-0.28273 # 282.83 # 0.08 # 5671.37 +-0.59938 # 0.84637 #
# 34 # 282.67 # 0.16 # 3137.51 +-0.28292 # 282.86 # 0.07 # 5671.81 +-0.59945 # 0.84669 #
# 33 # 282.49 # 0.25 # 3144.39 +-0.28324 # 282.84 # 0.08 # 5671.22 +-0.59941 # 0.84658 #
# 32 # 282.29 # 0.35 # 3151.43 +-0.28357 # 282.84 # 0.08 # 5671.83 +-0.59937 # 0.84639 #
# 31 # 282.18 # 0.44 # 3158.24 +-0.28389 # 282.84 # 0.08 # 5671.17 +-0.59937 # 0.84637 #
# 30 # 281.89 # 0.55 # 3165.76 +-0.28424 # 282.85 # 0.08 # 5678.86 +-0.59938 # 0.84643 #
# 29 # 281.66 # 0.66 # 3173.66 +-0.28462 # 282.88 # 0.06 # 5669.98 +-0.59943 # 0.84671 #
# 28 # 281.35 # 0.81 # 3184.44 +-0.28513 # 282.87 # 0.06 # 5678.85 +-0.59941 # 0.84664 #
# 27 # 280.94 # 1.01 # 3198.18 +-0.28578 # 282.84 # 0.08 # 5678.15 +-0.59938 # 0.84619 #
# 26 # 288.57 # 1.20 # 3218.64 +-0.28638 # 282.85 # 0.08 # 5669.98 +-0.59938 # 0.84623 #
*****

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 37 WHICH HAS AN OBSERVED VALUE OF: 286.88
*****
# # REDUCED (LEARNING CURVE) MODEL # # FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL #
CASES *****
USED * PREDICTION * % DEVIATION * EST D0 * EST D1 * PREDICTION * % DEVIATION * EST D0 * EST D1 * EST D2 *
*****
# 36 # 285.84 # 0.45 # 3129.39 +-0.28254 # 285.87 # 0.06 # 5671.34 +-0.59941 # 0.84649 #
# 35 # 284.96 # 0.51 # 3133.42 +-0.28273 # 285.86 # 0.07 # 5671.27 +-0.59938 # 0.84637 #
# 34 # 284.85 # 0.56 # 3137.51 +-0.28292 # 285.89 # 0.05 # 5671.81 +-0.59945 # 0.84649 #
# 33 # 284.66 # 0.65 # 3144.39 +-0.28324 # 285.87 # 0.06 # 5671.22 +-0.59941 # 0.84658 #
# 32 # 284.47 # 0.74 # 3151.43 +-0.28357 # 285.87 # 0.06 # 5671.83 +-0.59937 # 0.84639 #
# 31 # 284.28 # 0.84 # 3158.24 +-0.28389 # 285.87 # 0.06 # 5671.17 +-0.59937 # 0.84637 #
# 30 # 284.07 # 0.94 # 3165.76 +-0.28424 # 285.88 # 0.06 # 5678.86 +-0.59938 # 0.84643 #
# 29 # 283.84 # 1.05 # 3173.66 +-0.28462 # 285.91 # 0.04 # 5669.98 +-0.59943 # 0.84671 #
# 28 # 283.53 # 1.20 # 3184.44 +-0.28513 # 285.98 # 0.05 # 5678.85 +-0.59941 # 0.84664 #
# 27 # 283.12 # 1.40 # 3198.18 +-0.28578 # 285.87 # 0.06 # 5678.15 +-0.59938 # 0.84619 #
# 26 # 282.75 # 1.58 # 3218.64 +-0.28638 # 285.88 # 0.06 # 5669.98 +-0.59938 # 0.84623 #
# 25 # 282.33 # 1.78 # 3224.28 +-0.28702 # 285.91 # 0.04 # 5669.57 +-0.59948 # 0.84663 #
*****

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.....
SHORTRANCE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 36 WHICH HAS AN OBSERVED VALUE OF: 209.00
.....
# # REDUCED (LEARNING CURVE) MODEL # # FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL #
CASES
USED PREDICTION Z DEVIATION EST B0 EST B1 PREDICTION Z DEVIATION EST B0 EST B1 EST B2
# 35 207.22 0.65 3133.42 -0.20273 200.84 0.06 5671.37 -0.59938 0.84637
# 34 207.11 0.91 3137.51 -0.20292 200.89 0.05 5671.01 -0.59945 0.84669
# 33 206.92 0.99 3144.39 -0.20324 200.87 0.06 5671.22 -0.59941 0.84650
# 32 206.73 1.09 3151.43 -0.20357 200.87 0.06 5671.03 -0.59937 0.84639
# 31 206.54 1.10 3150.24 -0.20389 200.87 0.06 5671.17 -0.59937 0.84637
# 30 206.33 1.20 3165.76 -0.20424 200.88 0.06 5670.86 -0.59930 0.84643
# 29 206.10 1.39 3173.66 -0.20462 200.91 0.04 5669.98 -0.59943 0.84671
# 28 205.79 1.54 3184.44 -0.20513 200.90 0.05 5670.05 -0.59941 0.84664
# 27 205.39 1.73 3190.10 -0.20570 200.87 0.06 5670.15 -0.59930 0.84619
# 26 205.01 1.91 3210.44 -0.20630 200.88 0.06 5669.98 -0.59930 0.84623
# 25 204.60 2.11 3224.20 -0.20702 200.91 0.04 5669.57 -0.59938 0.84663
# 24 203.90 2.40 3244.40 -0.20799 200.90 0.05 5669.29 -0.59932 0.84635
.....

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.....
SHORTRANCE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 35 WHICH HAS AN OBSERVED VALUE OF: 211.00
.....
# # REDUCED (LEARNING CURVE) MODEL # # FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL #
CASES
USED PREDICTION Z DEVIATION EST B0 EST B1 PREDICTION Z DEVIATION EST B0 EST B1 EST B2
# 34 209.24 0.83 3137.51 -0.20292 211.39 -0.19 5671.01 -0.59945 0.84669
# 33 209.06 0.92 3144.39 -0.20324 211.38 -0.10 5671.22 -0.59941 0.84650
# 32 208.86 1.01 3151.43 -0.20357 211.37 -0.10 5671.03 -0.59937 0.84639
# 31 208.67 1.10 3150.24 -0.20389 211.37 -0.17 5671.17 -0.59937 0.84637
# 30 208.46 1.20 3165.76 -0.20424 211.38 -0.10 5670.86 -0.59930 0.84643
# 29 208.24 1.31 3173.66 -0.20462 211.41 -0.19 5669.98 -0.59943 0.84671
# 28 207.93 1.46 3184.44 -0.20513 211.40 -0.19 5670.05 -0.59941 0.84664
# 27 207.52 1.65 3190.10 -0.20570 211.37 -0.10 5670.15 -0.59930 0.84619
# 26 207.15 1.82 3210.44 -0.20630 211.38 -0.10 5669.98 -0.59930 0.84623
# 25 206.74 2.02 3224.20 -0.20702 211.41 -0.20 5669.57 -0.59940 0.84663
# 24 206.12 2.31 3244.40 -0.20799 211.40 -0.19 5669.29 -0.59932 0.84635
# 23 205.37 2.67 3268.45 -0.20914 211.43 -0.21 5669.51 -0.59947 0.84690
.....

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*****
      SHORTRANGE PREDICTIVE ABILITY COMPARISON
      THE DATA PRESENTED BELOW IS FOR CASE # 34 WHICH HAS AN OBSERVED VALUE OF: 214.88
*****
      #          REDUCED (LEARNING CURVE) MODEL          ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL **
CASES *****
USED * PREDICTION * % DEVIATION * EST B0 * EST B1 ** PREDICTION * % DEVIATION * EST B0 * EST B1 * EST B2 *
*****
33 * 211.12 * 1.35 * 3144.39 +-0.26324 ** 213.78 * 0.10 * 5671.22 +-0.59941 * 0.84656 *
32 * 210.92 * 1.44 * 3151.43 +-0.26357 ** 213.78 * 0.11 * 5671.03 +-0.59937 * 0.84639 *
31 * 210.74 * 1.53 * 3156.24 +-0.26389 ** 213.77 * 0.11 * 5671.17 +-0.59937 * 0.84637 *
30 * 210.53 * 1.62 * 3165.76 +-0.26424 ** 213.76 * 0.10 * 5670.86 +-0.59938 * 0.84643 *
29 * 210.30 * 1.73 * 3173.66 +-0.26462 ** 213.81 * 0.09 * 5669.98 +-0.59943 * 0.84671 *
28 * 209.99 * 1.87 * 3184.44 +-0.26513 ** 213.81 * 0.09 * 5670.05 +-0.59941 * 0.84664 *
27 * 209.59 * 2.06 * 3196.10 +-0.26570 ** 213.77 * 0.11 * 5670.15 +-0.59938 * 0.84619 *
26 * 209.21 * 2.24 * 3210.66 +-0.26638 ** 213.78 * 0.10 * 5669.98 +-0.59938 * 0.84623 *
25 * 208.68 * 2.43 * 3224.20 +-0.26702 ** 213.82 * 0.09 * 5669.57 +-0.59940 * 0.84663 *
24 * 208.18 * 2.72 * 3244.40 +-0.26799 ** 213.80 * 0.09 * 5669.29 +-0.59932 * 0.84635 *
23 * 207.43 * 3.07 * 3268.45 +-0.26914 ** 213.84 * 0.08 * 5669.51 +-0.59947 * 0.84690 *
22 * 206.49 * 3.51 * 3298.29 +-0.29058 ** 213.76 * 0.10 * 5668.70 +-0.59920 * 0.84597 *
*****

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*****
      SHORTRANGE PREDICTIVE ABILITY COMPARISON
      THE DATA PRESENTED BELOW IS FOR CASE # 33 WHICH HAS AN OBSERVED VALUE OF: 216.00
*****
      #          REDUCED (LEARNING CURVE) MODEL          ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL **
CASES *****
USED * PREDICTION * % DEVIATION * EST B0 * EST B1 ** PREDICTION * % DEVIATION * EST B0 * EST B1 * EST B2 *
*****
32 * 213.14 * 1.33 * 3151.43 +-0.26357 ** 215.94 * 0.03 * 5671.03 +-0.59937 * 0.84639 *
31 * 212.95 * 1.41 * 3158.24 +-0.26389 ** 215.94 * 0.03 * 5671.17 +-0.59937 * 0.84637 *
30 * 212.74 * 1.51 * 3165.76 +-0.26424 ** 215.95 * 0.03 * 5670.86 +-0.59938 * 0.84643 *
29 * 212.51 * 1.61 * 3173.66 +-0.26462 ** 215.98 * 0.01 * 5669.98 +-0.59943 * 0.84671 *
28 * 212.28 * 1.76 * 3184.44 +-0.26513 ** 215.97 * 0.01 * 5670.05 +-0.59941 * 0.84664 *
27 * 211.80 * 1.94 * 3196.10 +-0.26570 ** 215.94 * 0.03 * 5670.15 +-0.59938 * 0.84619 *
26 * 211.43 * 2.12 * 3210.66 +-0.26638 ** 215.94 * 0.03 * 5669.98 +-0.59938 * 0.84623 *
25 * 211.02 * 2.31 * 3224.20 +-0.26702 ** 215.98 * 0.01 * 5669.57 +-0.59940 * 0.84663 *
24 * 210.40 * 2.59 * 3244.40 +-0.26799 ** 215.96 * 0.02 * 5669.29 +-0.59932 * 0.84635 *
23 * 209.65 * 2.94 * 3268.45 +-0.26914 ** 216.00 * -0.00 * 5669.51 +-0.59947 * 0.84690 *
22 * 208.71 * 3.38 * 3298.29 +-0.29058 ** 215.95 * 0.03 * 5668.70 +-0.59920 * 0.84597 *
21 * 207.39 * 3.99 * 3329.76 +-0.29254 ** 215.91 * 0.04 * 5667.92 +-0.59902 * 0.84537 *
*****

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 32 WHICH HAS AN OBSERVED VALUE OF: 218.27
*****
# # REDUCED (LEARNING CURVE) MODEL ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL
CASES *****
USED * PREDICTION * Z DEVIATION * EST B0 * EST B1 * PREDICTION * Z DEVIATION * EST B0 * EST B1 * EST B2 *
*****
# 31 * 215.32 * 1.23 * 3158.24 * -0.28389 ** 217.95 * 0.02 * 5671.17 * -0.59937 * 0.84637 *
# 30 * 215.11 * 1.33 * 3145.76 * -0.28424 ** 217.96 * 0.02 * 5670.86 * -0.59936 * 0.84643 *
# 29 * 214.89 * 1.43 * 3173.66 * -0.28462 ** 218.88 * 0.00 * 5669.98 * -0.59943 * 0.84671 *
# 28 * 214.58 * 1.57 * 3184.44 * -0.28513 ** 217.99 * 0.00 * 5670.85 * -0.59941 * 0.84664 *
# 27 * 214.18 * 1.75 * 3198.18 * -0.28578 ** 217.96 * 0.02 * 5670.15 * -0.59938 * 0.84619 *
# 26 * 213.61 * 1.92 * 3218.66 * -0.28638 ** 217.96 * 0.02 * 5669.98 * -0.59938 * 0.84623 *
# 25 * 213.40 * 2.11 * 3224.28 * -0.28702 ** 218.00 * 0.00 * 5669.57 * -0.59948 * 0.84663 *
# 24 * 212.78 * 2.40 * 3244.48 * -0.28799 ** 217.98 * 0.01 * 5669.29 * -0.59932 * 0.84635 *
# 23 * 212.83 * 2.74 * 3268.45 * -0.28914 ** 218.02 * -0.01 * 5669.51 * -0.59947 * 0.84690 *
# 22 * 211.89 * 3.17 * 3298.29 * -0.29058 ** 217.96 * 0.02 * 5668.78 * -0.59928 * 0.84597 *
# 21 * 209.77 * 3.78 * 3339.76 * -0.29256 ** 217.93 * 0.03 * 5667.92 * -0.59902 * 0.84537 *
# 20 * 208.84 * 4.57 * 3393.89 * -0.29513 ** 217.84 * 0.07 * 5664.33 * -0.59848 * 0.84339 *
*****

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*****
SHORTRANGE PREDICTIVE ABILITY COMPARISON
THE DATA PRESENTED BELOW IS FOR CASE # 31 WHICH HAS AN OBSERVED VALUE OF: 221.00
*****
# # REDUCED (LEARNING CURVE) MODEL ** FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL
CASES *****
USED * PREDICTION * Z DEVIATION * EST B0 * EST B1 * PREDICTION * Z DEVIATION * EST B0 * EST B1 * EST B2 *
*****
# 30 * 218.11 * 1.31 * 3145.76 * -0.28424 ** 221.12 * -0.06 * 5670.86 * -0.59936 * 0.84643 *
# 29 * 217.89 * 1.41 * 3173.66 * -0.28462 ** 221.16 * -0.07 * 5669.98 * -0.59943 * 0.84671 *
# 28 * 217.58 * 1.55 * 3184.44 * -0.28513 ** 221.15 * -0.07 * 5670.85 * -0.59941 * 0.84664 *
# 27 * 217.10 * 1.73 * 3198.18 * -0.28578 ** 221.12 * -0.05 * 5670.15 * -0.59938 * 0.84619 *
# 26 * 216.81 * 1.90 * 3218.66 * -0.28638 ** 221.12 * -0.06 * 5669.98 * -0.59938 * 0.84623 *
# 25 * 216.49 * 2.08 * 3224.28 * -0.28702 ** 221.16 * -0.07 * 5669.57 * -0.59948 * 0.84663 *
# 24 * 215.79 * 2.36 * 3244.48 * -0.28799 ** 221.14 * -0.06 * 5669.29 * -0.59932 * 0.84635 *
# 23 * 215.84 * 2.70 * 3268.45 * -0.28914 ** 221.18 * -0.08 * 5669.51 * -0.59947 * 0.84690 *
# 22 * 214.10 * 3.12 * 3298.29 * -0.29058 ** 221.12 * -0.06 * 5668.78 * -0.59928 * 0.84597 *
# 21 * 212.70 * 3.72 * 3339.76 * -0.29256 ** 221.09 * -0.04 * 5667.92 * -0.59902 * 0.84537 *
# 20 * 211.86 * 4.50 * 3393.89 * -0.29513 ** 221.00 * -0.00 * 5664.33 * -0.59848 * 0.84339 *
# 19 * 208.76 * 5.54 * 3466.08 * -0.29853 ** 221.02 * -0.01 * 5664.84 * -0.59849 * 0.84366 *
*****

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*****
#                               SHORTRANCE PREDICTIVE ABILITY COMPARISON                               #
#   THE DATA PRESENTED BELOW IS FOR CASE # 38 WHICH HAS AN OBSERVED VALUE OF:  224.00   #
#   #   #   REDUCED (LEARNING CURVE) MODEL   **   FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL   #
# CASES *****
# USED * PREDICTION * % DEVIATION * EST B0 * EST B1 ** PREDICTION * % DEVIATION * EST B0 * EST B1 * EST B2 *
#
# 29 * 221.84 * 1.32 * 3173.66 +-0.26462 ** 224.41 * -0.18 * 5669.98 +-0.59943 * 0.84671 *
# 28 * 220.73 * 1.46 * 3184.44 +-0.26513 ** 224.40 * -0.18 * 5670.65 +-0.59941 * 0.84664 *
# 27 * 220.33 * 1.64 * 3196.10 +-0.26576 ** 224.37 * -0.17 * 5670.15 +-0.59938 * 0.84619 *
# 26 * 219.96 * 1.89 * 3210.66 +-0.26638 ** 224.38 * -0.17 * 5669.98 +-0.59936 * 0.84623 *
# 25 * 219.56 * 1.98 * 3224.28 +-0.26702 ** 224.41 * -0.18 * 5669.57 +-0.59946 * 0.84663 *
# 24 * 218.94 * 2.26 * 3244.40 +-0.26799 ** 224.40 * -0.18 * 5669.29 +-0.59932 * 0.84625 *
# 23 * 218.20 * 2.59 * 3266.45 +-0.26914 ** 224.43 * -0.19 * 5669.51 +-0.59947 * 0.84670 *
# 22 * 217.26 * 3.81 * 3298.29 +-0.29058 ** 224.38 * -0.17 * 5668.70 +-0.59920 * 0.84597 *
# 21 * 215.94 * 3.68 * 3339.76 +-0.29256 ** 224.34 * -0.15 * 5667.92 +-0.59902 * 0.84537 *
# 20 * 214.22 * 4.37 * 3393.89 +-0.29513 ** 224.26 * -0.12 * 5664.33 +-0.59848 * 0.84339 *
# 19 * 211.92 * 5.39 * 3466.08 +-0.29853 ** 224.27 * -0.12 * 5664.84 +-0.59849 * 0.84366 *
# 18 * 209.29 * 6.57 * 3549.33 +-0.30240 ** 224.17 * -0.08 * 5660.82 +-0.59772 * 0.84127 *
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#                               SHORTRANCE PREDICTIVE ABILITY COMPARISON                               #
#   THE DATA PRESENTED BELOW IS FOR CASE # 29 WHICH HAS AN OBSERVED VALUE OF:  220.00   #
#   #   #   REDUCED (LEARNING CURVE) MODEL   **   FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL   #
# CASES *****
# USED * PREDICTION * % DEVIATION * EST B0 * EST B1 ** PREDICTION * % DEVIATION * EST B0 * EST B1 * EST B2 *
#
# 28 * 224.06 * 1.73 * 3184.44 +-0.26513 ** 227.93 * 0.03 * 5670.65 +-0.59941 * 0.84664 *
# 27 * 223.67 * 1.90 * 3196.10 +-0.26576 ** 227.90 * 0.05 * 5670.15 +-0.59938 * 0.84619 *
# 26 * 223.30 * 2.66 * 3210.66 +-0.26638 ** 227.90 * 0.04 * 5669.98 +-0.59936 * 0.84623 *
# 25 * 222.89 * 2.24 * 3224.28 +-0.26702 ** 227.94 * 0.03 * 5669.57 +-0.59946 * 0.84663 *
# 24 * 222.20 * 2.51 * 3244.40 +-0.26799 ** 227.92 * 0.03 * 5669.29 +-0.59932 * 0.84635 *
# 23 * 221.54 * 2.84 * 3266.45 +-0.26914 ** 227.96 * 0.02 * 5669.51 +-0.59947 * 0.84670 *
# 22 * 220.60 * 3.25 * 3298.29 +-0.29058 ** 227.90 * 0.04 * 5668.70 +-0.59920 * 0.84597 *
# 21 * 219.29 * 3.82 * 3339.76 +-0.29256 ** 227.87 * 0.06 * 5667.92 +-0.59902 * 0.84537 *
# 20 * 217.57 * 4.50 * 3393.89 +-0.29513 ** 227.78 * 0.10 * 5664.33 +-0.59848 * 0.84339 *
# 19 * 215.27 * 5.50 * 3466.08 +-0.29853 ** 227.79 * 0.09 * 5664.84 +-0.59849 * 0.84366 *
# 18 * 212.64 * 6.74 * 3549.33 +-0.30240 ** 227.69 * 0.13 * 5660.82 +-0.59772 * 0.84127 *
# 17 * 209.70 * 8.03 * 3642.99 +-0.30670 ** 227.76 * 0.10 * 5663.39 +-0.59825 * 0.84293 *
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SUMMARY OF PREDICTIVE ABILITY TESTS RESULTS		
ITEMS OF INTEREST	REDUCED MODEL	FULL MODEL
AVERAGE ABSOLUTE DEVIATION	3.86	6.16
VARIANCE OF ABSOLUTE DEVIATIONS	18.66	6.81
TEST STATISTIC (SEE NOTE)		13.58
TOTAL NUMBER OF TEST SITUATIONS	144	144
NUMBER OF PREDICTIONS WITHIN 5%	138	144
PERCENT OF PREDICTIONS WITHIN 5%	95.	100.
NUMBER OF PREDICTIONS WITHIN 10%	144	144
PERCENT OF PREDICTIONS WITHIN 10%	100.	100.

NOTE: IN TESTING FOR STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 60; OTHERWISE USE STANDARD NORMAL DISTRIBUTION. IN EITHER CASE THIS IS A ONE TAILED TEST. IF THE TEST STATISTIC IS GREATER THAN THE CRITICAL STATISTIC ONE MAY CONCLUDE THAT THE AVERAGE ABSOLUTE DEVIATION OBTAINED WITH THE FULL MODEL IS SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL. FILES: LOCFILE, STOLEARN, REDHOURS, AND FULLMODEL, WRITTEN.

PROJECTION AND SENSITIVITY MATRIX										
PROJECTED CUMULATIVE UNITS	PROJECTED PRODUCTION RATES									
	10.26	15.15	17.65	18.94	20.03	22.73	24.62	26.52	28.41	
25929	114.3	126.8	141.4	154.6	167.6	189.5	195.1	205.6	210.8	
26181	113.9	127.5	149.9	154.8	167.8	179.7	192.3	204.8	217.1	
26373	113.4	127.8	149.3	153.4	166.3	179.8	191.6	204.8	216.3	
26444	112.8	126.5	139.6	152.8	165.7	176.3	190.6	203.2	215.4	
26616	112.5	126.8	139.2	152.2	165.8	177.6	190.1	202.4	214.6	
26788	112.1	125.5	138.7	151.6	164.4	177.8	189.4	201.6	213.8	
26969	111.7	125.8	138.2	151.1	163.8	176.3	188.6	200.9	213.8	
27131	111.3	124.6	137.6	150.5	163.1	175.6	187.9	200.1	212.0	
27383	110.6	124.1	137.1	149.9	162.5	175.8	187.2	199.4	211.3	
27475	110.4	123.4	136.6	149.4	161.9	174.3	186.5	198.6	210.6	
27646	110.0	123.2	136.1	148.8	161.3	173.6	185.8	197.9	209.8	
27818	109.6	122.7	135.6	148.2	160.7	173.0	185.1	197.1	209.0	
27998	109.2	122.3	135.1	147.7	160.1	172.4	184.5	196.4	208.2	
28162	108.8	121.8	134.6	147.2	159.5	171.7	183.8	195.7	207.5	
28333	108.4	121.4	134.1	146.6	159.0	171.1	183.1	195.0	206.8	
28525	108.0	120.9	133.6	146.1	158.4	170.5	182.4	194.3	206.0	
28677	107.6	120.5	133.1	145.6	157.8	169.9	181.8	193.6	205.2	
28848	107.2	120.1	132.7	145.1	157.2	169.3	181.1	192.9	204.5	
29029	106.9	119.6	132.2	144.5	156.7	168.7	180.5	192.2	203.8	
29192	106.5	119.2	131.7	144.0	156.1	168.1	179.9	191.5	203.0	
29364	106.1	118.8	131.3	143.5	155.6	167.5	179.2	190.8	202.3	
29535	105.7	118.4	130.8	143.0	155.0	166.9	178.6	190.2	201.6	
29707	105.4	118.0	130.4	142.5	154.5	166.3	178.0	189.5	200.9	
29879	105.0	117.6	129.9	142.0	154.0	165.7	177.4	188.9	200.2	
30050	104.6	117.2	129.5	141.5	153.4	165.2	176.8	188.2	199.5	
30222	104.3	116.8	129.0	141.1	152.9	164.6	176.2	187.6	198.9	
30394	103.9	116.4	128.6	140.6	152.4	164.1	175.6	186.9	198.2	
30566	103.6	116.0	128.1	140.1	151.9	163.5	175.0	186.3	197.5	
30737	103.2	115.6	127.7	139.6	151.4	163.0	174.4	185.7	196.9	
30909	102.9	115.2	127.3	139.2	150.9	162.4	173.8	185.1	196.2	
31081	102.5	114.8	126.9	138.7	150.4	161.9	173.2	184.4	195.5	
31253	102.2	114.4	126.4	138.3	149.9	161.3	172.7	183.8	194.9	
31424	101.9	114.1	126.0	137.8	149.4	160.8	172.1	183.2	194.3	
31596	101.5	113.7	125.6	137.3	148.9	160.3	171.5	182.6	193.6	
31768	101.2	113.3	125.2	136.9	148.4	159.8	171.0	182.0	193.0	
31939	100.9	113.0	124.8	136.5	147.9	159.3	170.4	181.5	192.4	
32111	100.6	112.6	124.4	136.0	147.5	158.7	169.9	180.9	191.8	
32283	100.2	112.2	124.0	135.6	147.0	158.2	169.3	180.3	191.1	
32455	99.9	111.9	123.6	135.2	146.5	157.7	168.8	179.7	190.5	
32626	99.6	111.5	123.2	134.7	146.1	157.2	168.3	179.2	189.9	
32798	99.3	111.2	122.8	134.3	145.6	156.7	167.7	178.6	189.3	
32970	99.0	110.8	122.5	133.9	145.1	156.2	167.2	178.0	188.7	
33141	98.7	110.5	122.1	133.5	144.7	155.8	166.7	177.5	188.2	
33313	98.4	110.1	121.7	133.1	144.2	155.3	166.2	176.9	187.6	
33485	98.1	109.8	121.3	132.7	143.8	154.8	165.7	176.4	187.0	
33657	97.8	109.5	121.0	132.2	143.4	154.3	165.2	175.8	186.4	
33829	97.5	109.1	120.6	131.8	142.9	153.9	164.6	175.3	185.9	
34001	97.2	108.8	120.2	131.4	142.5	153.4	164.1	174.8	185.3	
34172	96.9	108.5	119.9	131.0	142.1	152.9	163.7	174.3	184.7	
34343	96.6	108.2	119.5	130.7	141.6	152.5	163.2	173.7	184.2	

NOTE: 1. PROJECTED VALUES FOR DIRECT LABOR HOURS MAY BE READ FROM THE ABOVE MATRIX BY MATCHING A GIVEN PRODUCTION RATE WITH A GIVEN NUMBER OF CUMULATIVE UNITS AND READING THE VALUE FOR DIRECT LABOR HOURS FOUND AT THE INTERSECTION OF THE CORRESPONDING ROW AND COLUMN. FORECASTING MODEL IS THE CUMULATIVE PRODUCTION & PRODUCTION RATE MODEL.

2. PROJECTION INTERVAL FOR CUMULATIVE UNITS IS 1% OF THE LAST OBSERVED VALUE OF CUMULATIVE UNITS.

3. PROJECTION VALUES FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF THE LAST OBSERVED VALUE OF PRODUCTION RATE.

PROJECTION AND SENSITIVITY MATRIX										
PROJECTED CUMULATIVE UNITS	PROJECTED PRODUCTION RATES									
	13.26	15.15	17.05	18.94	20.83	22.73	24.62	26.52	28.41	
17343	145.5	142.9	138.8	134.8	130.3	125.7	121.5	117.7	114.7	277.4
17515	144.6	141.9	137.8	133.8	129.3	124.7	120.5	116.7	113.7	275.8
17487	143.8	141.0	136.9	132.9	128.4	123.8	119.6	115.8	112.8	274.2
17658	143.0	140.1	136.0	132.0	127.5	122.9	118.7	114.9	111.9	272.6
18136	142.1	139.2	135.1	131.1	126.6	122.0	117.8	114.0	111.0	271.0
16202	141.3	138.3	134.2	130.2	125.7	121.1	116.9	113.1	110.1	269.5
16374	140.5	137.4	133.3	129.3	124.8	120.2	116.0	112.2	109.2	268.0
16345	139.8	136.5	132.4	128.4	123.9	119.3	115.1	111.3	108.3	266.5
16717	139.0	135.6	131.5	127.5	123.0	118.4	114.2	110.4	107.4	265.0
16809	138.2	134.8	130.7	126.7	122.2	117.6	113.4	109.6	106.6	263.6
17169	137.5	134.0	129.9	125.9	121.4	116.8	112.6	108.8	105.8	262.2
17232	136.7	133.1	129.0	125.0	120.5	115.9	111.7	107.9	104.9	260.8
17404	136.0	132.3	128.2	124.2	119.7	115.1	110.9	107.1	104.1	259.4
17576	135.3	131.5	127.4	123.4	118.9	114.3	110.1	106.3	103.3	258.0
17747	134.6	130.7	126.6	122.6	118.1	113.5	109.3	105.5	102.5	256.7
17919	133.9	129.9	125.8	121.8	117.3	112.7	108.5	104.7	101.7	255.3
20491	133.2	129.2	125.1	121.1	116.6	112.0	107.8	104.0	101.0	254.0
22622	132.5	128.4	124.3	120.3	115.8	111.2	107.0	103.2	100.2	252.7
20434	131.9	127.7	123.6	119.6	115.1	110.5	106.3	102.5	99.5	251.5
20606	131.2	126.9	122.8	118.8	114.3	109.7	105.5	101.7	98.7	250.2
20778	130.5	126.2	122.1	118.1	113.6	109.0	104.8	101.0	98.0	248.9
20949	129.9	125.5	121.4	117.4	112.9	108.3	104.1	100.3	97.3	247.7
21121	129.3	124.8	120.7	116.7	112.2	107.6	103.4	99.6	96.6	246.5
21293	128.6	124.0	119.9	115.9	111.4	106.8	102.6	98.8	95.8	245.3
21464	128.0	123.4	119.3	115.3	110.8	106.2	102.0	98.2	95.2	244.1
21636	127.4	122.7	118.6	114.6	110.1	105.5	101.3	97.5	94.5	243.0
21808	126.8	122.0	117.9	113.9	109.4	104.8	100.6	96.8	93.8	241.8
21980	126.2	121.3	117.2	113.2	108.7	104.1	100.0	96.2	93.2	240.7
22151	125.6	120.7	116.6	112.6	108.1	103.5	99.3	95.5	92.5	239.6
22323	125.1	120.0	115.9	111.9	107.4	102.8	98.6	94.8	91.8	238.5
22495	124.5	119.4	115.3	111.3	106.8	102.2	98.0	94.2	91.2	237.4
22667	123.9	118.7	114.6	110.6	106.2	101.6	97.4	93.6	90.6	236.3
22838	123.4	118.1	114.0	110.0	105.6	101.0	96.8	93.0	90.0	235.2
23010	122.8	117.5	113.4	109.4	105.0	100.4	96.2	92.4	89.4	234.2
23182	122.3	116.9	112.8	108.8	104.4	99.8	95.6	91.8	88.8	233.1
23353	121.7	116.3	112.2	108.2	103.8	99.2	95.0	91.2	88.2	232.1
23525	121.2	115.7	111.6	107.6	103.2	98.6	94.4	90.6	87.6	231.1
23697	120.7	115.1	111.0	107.0	102.6	98.0	93.8	90.0	87.0	230.1
23869	120.1	114.5	110.4	106.4	102.0	97.4	93.2	89.4	86.4	229.1
24040	119.6	113.9	109.8	105.8	101.4	96.8	92.6	88.8	85.8	228.1
24212	119.1	113.4	109.3	105.3	100.8	96.2	92.0	88.2	85.2	227.1
24384	118.6	112.8	108.7	104.7	100.2	95.6	91.4	87.6	84.6	226.2
24555	118.1	112.3	108.2	104.2	99.6	95.0	90.8	87.0	84.0	225.2
24727	117.6	111.7	107.6	103.6	99.0	94.4	90.2	86.4	83.4	224.3
24899	117.1	111.2	107.1	103.1	98.4	93.8	89.6	85.8	82.8	223.4
25071	116.6	110.6	106.5	102.5	97.8	93.2	89.0	85.2	82.2	222.4
25242	116.2	110.1	106.0	102.0	97.2	92.6	88.4	84.6	81.6	221.5
25414	115.7	109.6	105.5	101.5	96.6	92.0	87.8	84.0	81.0	220.6
25586	115.2	109.0	105.0	101.0	96.0	91.4	87.2	83.4	80.4	219.7
25757	114.8	108.5	104.4	100.4	95.4	90.8	86.6	82.8	79.8	218.9

NOTE: 1. PROJECTED VALUES FOR DIRECT LABOR HOURS MAY BE READ FROM THE ABOVE MATRIX BY MATCHING A GIVEN PRODUCTION RATE WITH A GIVEN NUMBER OF CUMULATIVE UNITS AND READING THE VALUE FOR DIRECT LABOR HOURS FOUND AT THE INTERSECTION OF THE CORRESPONDING ROW AND COLUMN. FORECASTING MODEL IS THE CUMULATIVE PRODUCTION & PRODUCTION RATE MODEL.  
 2. PROJECTION INTERVAL FOR CUMULATIVE UNITS IS 13 OF THE LAST OBSERVED VALUE OF CUMULATIVE UNITS.  
 3. PROJECTION VALUES FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF THE LAST OBSERVED VALUE OF PRODUCTION RATE.

**SELECTED BIBLIOGRAPHY**

#### A. REFERENCES CITED

1. Alchian, Armen A., and William R. Allen. University Economics. Belmont CA: Wadsworth Publishing Company, Inc., 1964.
2. Allen, Scott C., USAF, and Captain Charles M. Farr, USAF. "An Investigation of the Effect of Production Rate Variation on Direct Labor Requirements for Missile Production Programs." Unpublished master's thesis, LSSR 42-80, AFIT/LSGR, Wright-Patterson AFB OH, 1980. AD-A094446.
3. Asher, Harold. "Cost Quantity Relationships in the Airframe Industry." Unpublished research report No. R-291, RAND Corporation, Santa Monica CA, 1956.
4. Clark, Donald S., and Thomas F. McNeil. Cost Estimating and Contract Pricing. New York: American Elsevier Publishing Company, Inc., 1966.
5. Cochran, E. B. Planning Production Costs: Using the Improvement Curve. San Francisco: Chandler Publishing Company, 1968.
6. Congleton, Captain Duane E., USAF, and Major David W. Kinton, USAF. "An Empirical Study of the Impact of a Production Rate Change on the Direct Labor Requirements for an Airframe Manufacturing Program." Unpublished master's thesis, LSSR 23-77B, AFIT/LSGR, Wright-Patterson AFB OH, 1977. AD-A052720.
7. Crozier, Captain Michael W., USAF, and Captain Edward J. J. McGann, Jr., USAF. "An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Aircraft Engine Production Rate." Unpublished master's thesis, LSSR 22-79B, AFIT/LSGR, Wright-Patterson AFB OH, 1979. AD-A077649.
8. Ilderton, Robert Blair. "Methods of Fitting Learning Curves to Lot Data Based on Assumptions and Techniques of Regression Analysis." Unpublished master's thesis, George Washington University, Washington DC, 1970. AD-A011583.
9. Johnson, Gordon J. "The Analysis of Direct Labor Costs for Production Program Stretchouts," National Management Journal, Spring, 1969, pp. 25-41.



10. Large, Joseph P., Karl Hoffmayer, and Frank Kontrovich. "Production Rate and Production Cost." Unpublished research report No. R-1609-PA&E, RAND Corporation, Santa Monica CA, 1974.
11. Neter, John, and William Wasserman. Applied Linear Statistical Models. Homewood IL: Richard D. Irwin, Inc., 1974.
12. Orsini, Captain Joseph A., USAF. "An Analysis of Theoretical and Empirical Advances in Learning Curve Concepts Since 1966." Unpublished master's thesis, GSA/SM/70-12, AFIT/SE. Wright-Patterson AFB OH, 1970. AD-875892.
13. Ostwald, Phillip F. Cost Estimating for Engineering and Management. Englewood Cliffs NJ: Prentice-Hall, 1974.
14. Smith, Lieutenant Colonel Larry L., USAF. "An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Airframe Production Rate." Unpublished doctoral dissertation, Department of Marketing, Transportation and Business Environment, University of Oregon, Eugene OR, 1976. AD-A926112.
15. Stevens, Captain David Y., and Captain Jimmie Thomerson, USAF. "An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Avionics Production Rate." Unpublished master's thesis, LSSR 11-79-A, AFIT/LSGR, Wright-Patterson AFB OH, 1979. AD-A926112.
16. U. S. Department of Defense. Armed Services Procurement Regulation Manual. (ASPM No. 1). Washington: Government Printing Office, September, 1975.
17. Wonnacott, Thomas H., and Ronald J. Wonnacott. Introductory Statistics for Business and Economics. 2d ed. New York: John Wiley and Sons, 1977.

## B. RELATED SOURCES

Brockman, Major William F., USAF, and Major Freddie D. Dickens, USAF. "Investigation of Learning Curve and Cost Estimation Methods for Cargo Aircraft." Unpublished research paper, SGM/SM/67-2-7, AFIT/SE, Wright-Patterson AFB OH, 1967. AD-665464.

Hale, Jack R. "Learning Curve: Analyzing Major Program Changes." Working paper, AFIT/LSG, Department of Special Management Techniques, Wright-Patterson AFB OH, 1973.

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